Vascular Occlusion Training as an Alternate Method of Gaining Muscle

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Abstract - *Training whilst under the effects of vascular occlusion has become increasingly popular due to the resultant muscle gain associated with this training technique. However, when exercising with the use of a tourniquet type device, it is possible for the pressure being applied to be inconsistent, due the constantly changing cross sectional area of the limb being occluded. This Paper describes the design of a device capable of causing vascular occlusion, but also being able to maintain a stable pressure required to create the blood flow restriction, this being able to be utilized in a sports science environment*

Keywords: Kaatsu training, muscle growth, vascular occlusion filtering.

1 Introduction

When attempting to gain muscle mass, it is currently known that a possible way to reach this goal is to lift large weights at high intensities, often around 70% of the maximum possible weight a person can lift for one repetition (1RM). For this method to be effective at increasing muscle mass, it is currently believed that the weight lifted should be a minimum of 65% of 1RM, as anything less than this will result in very little or even negligible muscle mass gain. However, optimally the intensity would be 75-80% of 1RM **[1]**.

For this method of training to be effective in building muscle mass, it is required to be completed roughly three or four times per week, completing up to three or four sets until exhaustion in each training session **[2]**. While this method has been proven to work as a way of building muscle mass, it results in high stress on the working muscles and joints, as well as being physically dangerous for particular individuals such as the elderly or the injured to complete. However, research has shown that an alternate method of gaining muscle exists, that being to induce occlusion to specific muscles, those being either in the arm or leg, and then to complete a lower-intensity workout, around 30-40% of 1RM. This method of low intensity training with induced muscle occlusion is commonly referred to as the Kaatsu method, or Kaatsu resistance training. **[3]**

With a system in place able to control the blood flow of the extremities in place, it is possible to have multiple versions of this system on multiple limbs, therefore working in unison to control the blood flow of the user. Such a system would require the communication of each device to other devices, possibly in addition to other gym equipment.

2 Background

Low intensity training with vascular occlusion offers many advantages compared to its counterpart. For example, if a participant is elderly, or if an individual may be unable to complete an exercise routine consisting of excessive weights, as it may be unsafe to do so, but may still wish to expand muscle mass. This method gives a valid alternative to maintain muscle mass with a method that possibly results in more mass gained than the traditional counterpart **[4]**. It has also been shown that a traditional workout may not be required to gain muscle mass while occlusion is being used, as activities such as walking with vascular occlusion on the leg muscles results in muscle gain **[5]**, with studies showing an increase in cross-sectional area in the region of anywhere between four and seven percent after three weeks of training.

The uses for this technique also extend to athletes at the elite level of their sport, where the idea of quickly building muscle mass without the risk of damaging or overusing those muscles may be appealing. While there may be less studies on this demographic than other areas, such as in the elderly, muscle occlusion while training at low intensities has been shown to increase the performance of athletes in some areas of track and field events already **[6]**. This method also has the advantage of reducing recovery time between workouts, and in some instances allows for multiple sessions in a single day, or at least more sessions that the average week would allow for if a different, more intensive, method were to be chosen.

Low intensity training has also been shown to induce less stress on the anatomical structures and physiological systems of the body to that of the high intensity counterpart. It has already been shown that low-intensity training sessions can benefit people with heart disease or other related issues **[2]**.

It has also been shown that when recovering from an injury, the application of muscle occlusion can benefit the recovery of muscle mass, resulting in less muscle mass lost during the recovery time.

It is believed that this growth of muscle mass is caused by an increased level of hormones responsible for the growth of muscle after low intensity training with muscle occlusion. It has been shown that after high intensity training, at 80% 1RM, the body releases these growth hormones to assist in muscle growth. It has also been shown that with muscle occlusion techniques and low workloads, those being 20% of 1RM; also result in a much higher quantity of these hormones being released **[7]**.

Currently, apparatuses designed to induce this occlusion in a gym like environment have been very limited; however, many alternatives have been used. These include devices such as tourniquets **[8]** or even elastic cuffs. Neither of these options however offers a way to react to changes in pressure in the cuff. In addition to this, having multiple cuffs working in parallel in addition to working with the gym equipment offers a unique method of gaining muscle mass that provides more options for the standard person to gain muscle mass.

3 The Kaatsu Method Of Muscle Training

As stated previously, the Kaatsu method of training involves restricting blood flow to specific muscles through the use of a tourniquet type device, and then completing a low intensity training session. By using a lower intensity, the amount of strain required of the muscles is greatly reduced. It has also been shown that there is a very low mechanical stress applied to the muscles when using this training method, and that due to this, muscle wear is much less, but also the recovery time is greatly reduced.

Due to the much smaller recovery time, it has been shown that advantages to elite athletes using this training method exist, as in some cases, the Kaatsu resistance training can be used without needing to alter the current training activities, as the muscles will still be able to complete other exercises after a session **[6]**. This behaviour was utilised by the athletes, allowing for more training of the muscles, resulting in better athletic results. Interestingly, these results were only in the events requiring sprinting, but not jumping.

The Kaatsu method was first attempted on the leg muscles, but after much refinement, was able to be used on the upper extremities as well **[3]**. It was not until 1983 however, that this method of training became available to the public.

Currently, Kaatsu training has been utilised by people of all ages, with, at the time of the national survey in 2006, 45.4% male and 54.6% female participants **[9]**. This same study, whilst establishing the safety of this training method, found that side effects of training under vascular occlusion were present in less than .06% of the population, with venous thrombus (0.055% of participants), pulmonary embolism (0.008% of participants) and rhabdomyolysis (0.008% of participants) being the most frequent. Due to this, it was determined that the Kaatsu training method was safe, not only to the elite athletes, but also to the general population, including the elderly.

Figure 1: Training cuffs utilized in Kaatsu training (Kaatsu master™) [15]

This method was originally developed in Japan, and is still being developed, with research being done in the fields of increase in muscle cross sectional area [**10**], muscle size/strength and endurance [**2**], possibilities of using Kaatsu training to prepare for space travel **[3][11]** and using the Kaatsu method to assist in injury recovery in race horses [**12**], and when utilized in patients recovering from a stroke, initial findings have shown positive improvements, although more research will need to be done in this area **[13]**.

When studying changes in muscle cross sectional area when undertaking Kaatsu training, a pressure of 160-240 mmHg was applied to the muscles. It should be noted that the goal of Kaatsu training is not to completely cut off blood flow, as training under these circumstances has been known to cause injury. This study **[10]** showed the advantages of using vascular occlusion at low intensity training compared to no vascular occlusion, with a 7.8% increase in cross sectional area while utilizing vascular occlusion, compared to the 1.8% increase without.

It was also shown, when studying the effects of arterial compliance, that being the blood arteries ability to expand and recoil, that short term resistance training had no negative effect on the participants **[14]**. However, this was also seen to be true of those participants utilizing high intensity training sessions without blood flow restrictions.

It is a well-known fact that Japan, the origin of Kaatsu training, is facing the possibility of an aging population, and it is the hope of those researching Kaatsu training that it will be utilized in an attempt to lessen the impact of this.

4 Purpose

Under normal circumstances, when training under vascular occlusion, a tourniquet or cuff has been used.

However, with the constant moving of limbs, the cross sectional area of the arm will change, meaning that the circumference, and therefore the tourniquet will also be affected. This can lead to a change in pressure applied to the limb, and therefore inconsistent pressure over the entire workout. As well as this, it means that a single pressure cannot be applied. It is aimed to create a cuff that is able to create a restriction in blood flow, that can also maintain a single pressure thorough the entire workout to alleviate this problem.
In addition to this, having a device that is able to communicate with multiple other systems in a gym environment, such as the equipment being used, as well as other cuffs on different limbs, allows for a more unique gym environment that gives the user more control over their environment. By allowing multiple cuffs to simultaneously be applied to multiple limbs ensures that consistency can be assured.

In addition to this, varying the pressure output of the cuffs over the gym session in addition to or as a substitute of varying the required intensity of the workout may be beneficial. To have the pressure cuff system operating within a gym type environment, it is possible for it to communicate to all other systems, such as 'smart' gym equipment to give the user more control of their experience.

5 Proposed solution

The pressure cuff is to be composed of a DC motor powered air compressor, solenoid release valve and variable capacitor. The device will be controlled by an Arduino Uno development board. To allow for the correct required number of inputs and outputs, it was decided to have the LCD screen and input button and LED outputs powered from the digital I/O pins, while things such as the pressure, as well as the activation signal for the MOSFET controlling the motor and solenoid valve would be controlled using the analogue pins. While not essential, these analogue pins would be read as digital pins, allowing for all required functionality to be gained. The below described controlling board contains the minimum for project completion. User controller buttons and LCD displays can be directly connected to the Arduino development board at a later stage.

6 Measuring pressure

The key component of the circuit for the task of measuring pressure is the variable capacitor with an air pressure sensitive ground plate. By measuring the capacitance value of this part we are able to determine the current pressure readings. The capacitor gives off a linear variance output.

In order to measure the capacitance through a microcontroller a 555 timer circuit is to be used. The circuit can be seen in Figure 2. It contains the 555 IC, two resistors and the variable capacitor. The circuit is powered directly from the Arduino development board through pins 8, 9. The function of the circuit is to produce a waveform on pin 3 (Port A0 on microcontroller) with varying frequency. R1 is chosen as 6.6M Ω and R2 as 3.3M Ω. With the minimum capacitance value of 13pF the frequency is 10 kHz and at the increased pressure of approximately 200pF the frequency is decreased to 1 kHz. These resistors can be decreased in value to produce a faster waveform.

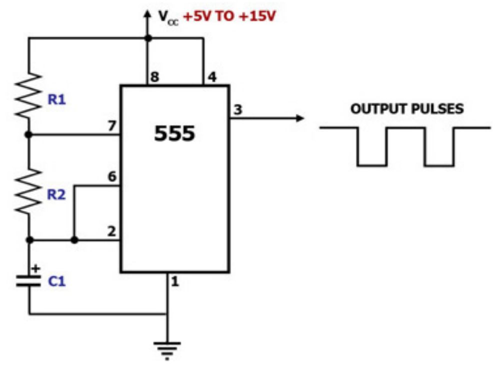

Figure 2: 555 timer circuit

These resistor values were chosen as it produces a square wave that has the 'on' phase of the wave twice the time period of the 'off' phase. Below are the equations that can be used to manually calculate wave form output time periods.

$t_1 = 0.693 (R_1 + R_2) C_1$
$t_2 = 0.693 (R_2) C_1$
Time Period Equations

It was found through doing these calculations, as well as testing the output of the I.C. chip through an oscilloscope, that the waveform output could have a difference of roughly 120 microseconds, meaning that the difference in lengths could easily be measured using the interrupts and a timer.

Once this had been done, it was required to program the ability for the microprocessor to measure the capacitance with this waveform. This was done by measuring the time it took for one wavelength to occur, and then converting this time into the corresponding pressure.

After initial tests, it was found that the value returned from a single measurement of pressure was affected by things such as noise of the system, to the point where the value showed variance when being held at a stable pressure. To try and minimize the interference, the average value of twenty measurements is used in all calculations.

7 Maintaining pressure

In order to maintain the pressure within the cuff, both a motor and a solenoid valve were utilized, both reacting to the change in pressure measured by the capacitor.

The motor and solenoid are only required to pass current in a single direction and as a result of this a simple transistor circuit is employed for each device. The transistors used are MOSFET devices with a maximum current rating of 17Amp. A safety reverse flow diode is included for extra transistor protection. The Solenoid and Motor are powered from a power source separate from that controlling the 555 timer, although still having a common ground.

8 Casing

It was initially decided to recycle a blood pressure monitor in order to house all of the components. This provided the benefit of already having a functioning mounting for the motor and pressure cuff. It also has a button already installed onto the case, and while not connected to the circuit board, alterations were made to ensure it was, and thus the functionality would not be lost.

However, once this idea was attempted, it became clear that a larger case was required. A new design was created that allowed for all inputs from the user to be easily accessible, while still being able to present all the required information. By designing a new case, it also allowed for different power supply options, as the previous case only allowed for four 1.5V batteries. Due to this, it was decided to implement a 12V input socket, and to have all devices being able to run from this.

Figure 3: Original blood pressure monitor

A momentary switch and sliding switch were also installed on the front of the case, as well as two LED's and the LCD screen. These served the function of being able to provide feedback to the user, as well as being able to accept the user's commands.

Once the new case had been designed, it was still possible to recycle sections of the blood pressure monitor, mainly the arm cuff, as well as the valve connecting the internal components, those being the pump, solenoid and capacitor, to the cuff. By recycling these two components, it was ensured that the entire tubing within the device would be airtight, as any leak could render the entire system incapable of reaching the desired pressure.

The Case is made from plastic, and is held together with four screws at each corner. The Microprocessor was mounted onto the case with a hot glue gun, as was the solenoid, motor and the casing for the capacitor. The capacitor itself is not held into place, however the tube it is connected to is mounted in a way that severely limits the capacitors freedom of movement, but still allows for the movement response due to differences in pressure to be measured. The circuit board is mounted above the corner of the microprocessor with a single screw that is also responsible for securing the voltage divider.

It was decided not to glue the valve leading to the pressure cuff onto the casing, as if this was done, opening the case would have become a much more tedious and laborious task. Instead, the valve is able to slide from the case when the outer casing is being removed. Alterations were made to the valve to ensure that the connection was secure, and that while active, minimal movement was possible, and any is not noticed.

The LCD screen was mounted to the top of the front panel with the two LED's underneath. The screen was mounted on with hot glue, but the LED's were screwed in, as was possible due to their casing. The momentary button and on/off switch were mounted in a similar fashion, however, due to the high profile of the connectors, they needed to be placed in a way that ensured they did not come into contact with the microprocessor, and were therefore placed in locations where the available room inside the casing was sufficient.

Figure 4: Design of the outer casing for the occlusion cuff

Figure 5: Design of the outer casing for the occlusion cuff, showing the connection plug to the occlusion cuff

Figure 6: Design of the outer casing for the occlusion cuff, showing the power adaptor input

9 Inputs

Apart from measuring the pressure in the cuff, the design needed to be able to have the user input specific information into the device. It was required to have the user select a value as the cuff was inflating, and when this value was selected, to have it remain stable. To do this, a single momentary button was utilized. This button initially replaced one of the LED's on the board, and was implemented in a way that made it active high. It was also required to have an on/off switch, which was also installed into the device. The device must also be capable of communicating with other devices in the system, such as the gym equipment it is attached to, and therefore communication between the device and others is handled via the serial communication outputs.

10 Results

The output voltage of the 555 timer is shown in Fig.7 and Fig.8. Fig. 7 shows the pressure when the cuff if sully inflated, while Fig. 8 shows the pressure output while the cuff is at rest. The overall pressure in the cuff is determined by measuring the time these outputs are high, as shown in Fig. 9.

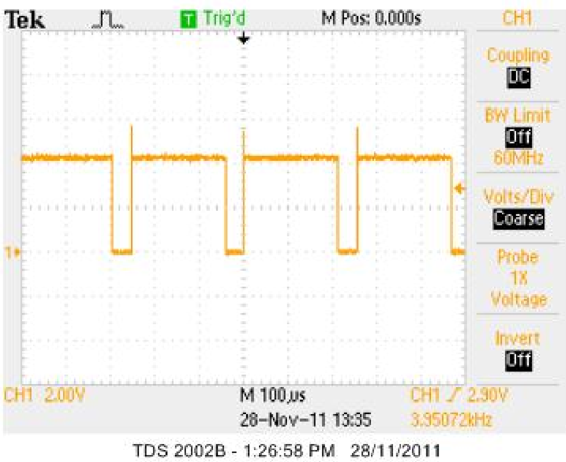

Figure 7: Reading from 555 timer when the cuff is at rest

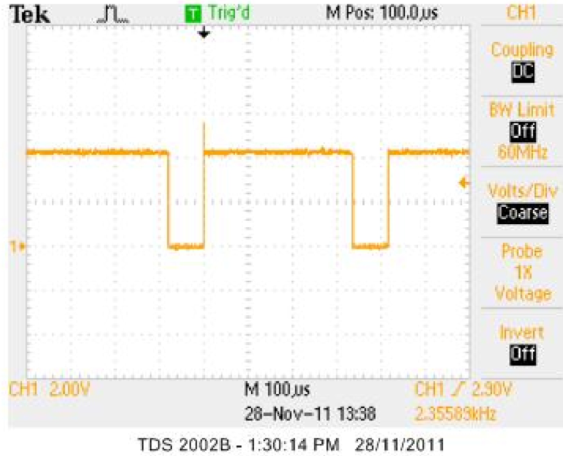

Figure 8: Reading from 555 timer when the cuff is fully inflated

It can be seen from the above figures that the output ranged from roughly 210µs to 320µs. These measurements were taken in order to assure the functionality of the 555 timer output, and therefore needed to be converted into the pressure outputs of the cuff.

After it was established that the pressure differences would be easily readable, it was required to have the outputted values mapped to their corresponding pressure. The system would output a number between 120 and 400 depending on the pressure applied. Given that the reasonable operating range of this device is much smaller than that, only the working range of the cuff was required.

Once this was established, the corresponding values of the output of the device and their related pressure could be determined. This is shown in the below table.

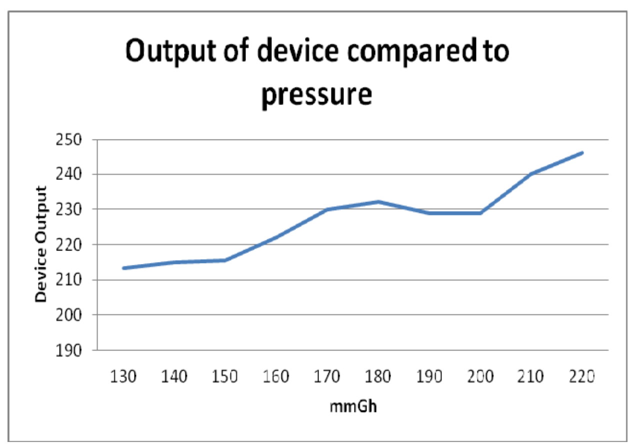

Figure 9: Output of the cuff over a range of pressures

The outputs shown in Fig. 9 represent the outputs of the device in a section of its operating range. In a future iteration of this device, this error will be further reduced to ensure the accuracy and therefore the reliability of this system.

11 Conclusion

The final iteration of the device contains a motor and solenoid valve for controlling the pressure in the cuff, with a capacitor able to react to the change in pressure, and therefore monitor the required changes, but also the resultant pressure due to these changes. The pressure is displayed on an LCD screen, and the device is easily controlled by the user, as all inputs are easy to use. The power supply is simple to use, and requires no change in batteries to maintain over an extended period of time. This allows for the device to be used in an exercise science type environment. In addition to this the device has the capability to communicate with other devices in a system, allowing for multiple occlusion cuffs to be used in tandem on multiple limbs, ensuring more control over the entire workout.

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