THE INFLUENCE OF WARM HYDROTHERAPY ON THE CARDIOVASCULAR SYSTEM AND MUSCLE RELAXATION

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Abstract

Five female and five male subjects with no known cardiovascular abnormalities nor any neuromuscular disorders were examined during exercise on a cycle ergometer or a 30 min immersion in warm water with and without exercise to determine the effects of immersion on cardiac output, heart rate, blood pressure, forearm blood flow, muscle blood flow, skin blood flow and muscle relaxation. Muscle relaxation was measured by the resistance to passively moving the leg through a 60° arc and by measurement of the Hoffman (H) reflex. The results of these experiments showed that 1) passive heating caused the greatest relaxation in muscle 2) most of the increase in blood flow to the limb during passive heating or exercise was to skeletal muscle 3) cardiac output increased modestly as did heart rate during passive exposure or light exercise in a therapeutic pool and 4) blood pressure was generally decreased during warm water immersion.

Key words: hydrotherapy, muscle, H-reflex, cardiac output, circulation, exercise

Introduction

Hydrotherapy has been used for thousands of years. Proto-Indian culture made use of hydrotherapy as far back as 2400 B.C. (Campion 1998). It was used by Hindus to combat fever as early as 1500 B.C., and has been used by Japanese, Greeks, Romans, and many other cultures (Campion 1998). As early as 1697, Sir John Floyer wrote a treatise on the use of hydrotherapy involving hot and cold water (Kamenetz 1963). While other uses of hydrotherapy involved medicinal remedies, in World War I and II hydrotherapy was used for maintenance of fitness (Krizek 1963). In recent years, hydrotherapy has become an integral part of physical therapy. Hydrotherapy has been attributed to promoting muscle relaxation (Moor et al. 1964) and increasing tissue temperature and tissue blood flow (Campion 1998; Cameron 1999). Three types of hydrotherapy can be used: neutrotherapy, thermotherapy, and cryotherapy, the difference being the varying temperature of the water (Campion 1999). Thermo-hydrotherapy is defined as the application of water to an immersed body at a temperature above skin temperature (Belanger 2002). Immersion in a water bath has been shown to be far more effective in increasing tissue temperature than hot packs, diathermy, or even ultrasound (Petrofsky and Laymon 2001; Clarke et al. 1958). Water is a very efficient way to warm tissue because of its high specific heat and thermal conductivity (Ruoti et al. 1997; Cameron 1999). It also provides a good medium for therapeutic exercise due to the buoyancy provided to the body reducing weight on joints (Petrofsky et al. 2001). Resistance to exercise is high due to the high viscosity of water (Cameron 1999).

It is certain that limb and muscle temperature increase with warm water immersion, however, the extent of increase in blood flow to the skin and muscle, and direct evidence of muscle relaxation have been poorly established with hydrotherapy. Even less evidence is found combining hydrotherapy with exercise.

Surely, whole limb blood flow increases with either exercise or exposure to a warm therapeutic pool (Greenberg 1972). This can be assessed with a Doppler flow meter or various types of volume plethysmography. For example, Clarke et al. (1958) showed an increase in limb blood flow by volume plethysmography that amounted to an approximate doubling in limb blood flow for every 2°C increase in limb temperature. However, it is not known if the flow increase is due to a dilation of skin vessels or an increase in muscle blood flow or both. It would be important to know if actual muscle blood flow increases in warm water since it is believed that warm water immersion is beneficial to muscle healing (Shankar and Randall 2002). Muscle blood flow is under autoregulation as well as neurogenic control. (Astrand and Rodahl 1970) Absent exercise, flow increase may be small to muscle and much of the increase in flow during warm immersion may be to the skin for thermoregulation. Equally, we would like to know whether or not warm water is sufficient in relaxing muscle.

In recent years, a technique of measuring alpha motor neuron excitability has been developed called the Hoffman, or the H-reflex. The H-reflex involves stimulating the motor nerve to a given muscle and assessing, through an electromyogram (EMG) above the active muscle, the response to a brief stimuli.(Oksa et al 2000) The muscle twitch that results from stimulation of the motor nerve has 2 components. The first is an M wave from the direct stimulation of the muscle. The second wave, H wave, results

from activation of sensory afferents that reflexively cause a muscle twitch through activation of the alpha motor neuron pool.(Bell and Lehmann 1987) The H wave and H/M ratio vary with alpha motor neuron pool excitability (Oksa et al. 2000). The H-reflex then, is a commonly accepted measure of motor neuron excitability (Bell and Lehmann 1987). While H-reflex studies have been used to study motor unit excitability in patients with cerebral palsy (Leonard et al. 1990), during gait (Burke et al. 1999), and after motor neuron damage (Leonard et al. 1998), few studies have looked at the effect of heating on both muscle relaxation and H-reflex activity. Interestingly, many studies on man and animals have looked at the effects of cooling on H-reflex activity. For example, Bell and Lehmann (1987) found that there were no changes in the H-reflex with cooling in humans. Chapman, et al. (1979) found that secondary spindle afferents did increase their response when cooled. In contrast, most studies show a reduced spindle activity with cooling, an increased H-reflex with cooling (Oksa et al. 2000; Sato 1983) and reduced reflex responses with heating (Pagliaro and Zamparo 1999). This leads to the belief that alpha motor neuron excitability and the H-reflex should be reduced with heating.

Therefore, in the present investigation, we attempted to conduct a more comprehensive study to provide a basis of evidence for the use of warm hydrotherapy with and without exercise influence on cardiac output, heart rate, blood pressure limb blood flow, skin blood flow, and muscle relaxation.

Methods

Subjects- Ten subjects participated in these experiments. The subjects were all physical therapy or medical students and ranged from 20 to 30 years old. Their weights were in the range of 50 to 100 kg and there was no restriction on height. The general characteristics of the subjects are shown in Table 1. One half of the subjects were male and half were female. All subjects were free from any neuromuscular disorders or any type of cardiovascular disease. All subjects read and signed a statement of informed consent as approved by the committee on human experimentation.

Table 1- General Characteristics of Subjects- all data shown +/- the SD

	Age (years)	Height(cm)	Weight (kg)	number
Males	24+/-2.4	173+/-6.4	84.2+/-16.1	5
Females	25+/-2.1	164.5+/-3.8	66.5+/-14.3	5
Group	24.3+/-2.3	169 +/- 6.2	75.1+/- 18.9	10

Measurement of Muscle Temperature- Muscle temperature was measured by a thermocouple probe inserted 1-2 cm below the surface of the skin, into the belly of the medial gastrocnemius muscle, so that the end of the probe was placed half way between the skin and center of the limb. A 22-gauge needle was first inserted into the muscle. A thermocouple was then placed down the shaft and the 22-gauge needle was withdrawn leaving the thermocouple buried in the muscle. Collodion was then applied around the thermocouple to assure a waterproof junction at the insertion point through the skin. The

thermocouple output was then displayed on a digital thermometer, where the temperature was read to ± 0.1°C.

EMG– Electromyogram (EMG) was recorded through two bipolar vinyl foam adhesive EMG electrodes (silver-silver chloride) with an active surface area of 0.5 cm^2. One electrode was placed over the belly of the active muscle. The second electrode was placed 2 cm distal to the active electrode. The EMG was amplified using a four-channel EMG amplifier with frequency response, which was flat from DC to 1000 Hz. The common mode rejection ratios of the amplifiers were greater than 120 Db. The EMG was digitized at 2000 samples per second and displayed and saved on an IBM computer for later analysis. To waterproof the electrodes, a layer of collodion was applied around and on top of the electrodes so that the electrodes would stick to the skin under water and the water would not seep under the electrodes and add to the impedance. We have used this technique previously and over a period as long as four hours. Throughout the testing period, there was no variation in EMG amplitude or electrode impedance (Petrofsky and Lind 1980). Others, who have not used a waterproofing agent, have shown a significant difference in EMG amplitude in water and on land for a given strength of muscle contraction (Poyhonen et al. 1999).

The H-Reflex- To quantify the H-reflex, electrical stimulation was applied by two electrodes above the motor nerve to the gastrocnemius muscle, and one ground electrode was applied to the Achilles tendon (Figure 1). Two bipolar electrodes were placed on the surface of the skin over the motor nerve approximately 6 inches from its insertion into the muscle over the popliteal fossa. An electrical stimulus (single impulse) was applied to elicit a muscle twitch. The stimulus amplitude peaked at 38 volts (V) and the pulse width

was 500 microseconds. The amplitude of the stimulus was increased in 2 V increments from 2 V to 38 V and the EMG above the muscle was recorded. The amplitude of the H wave, M wave and the time delay between the M and H wave were measured (Figure 2).

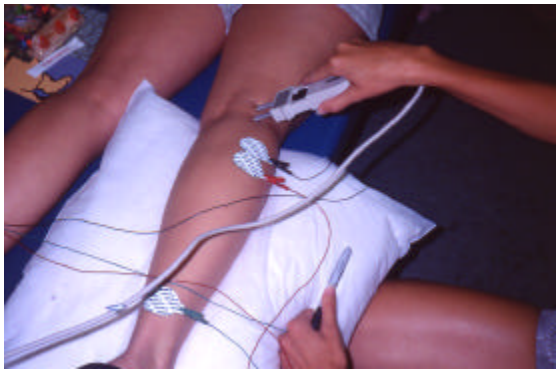

Figure 1- Electrode position for measuring the H reflex

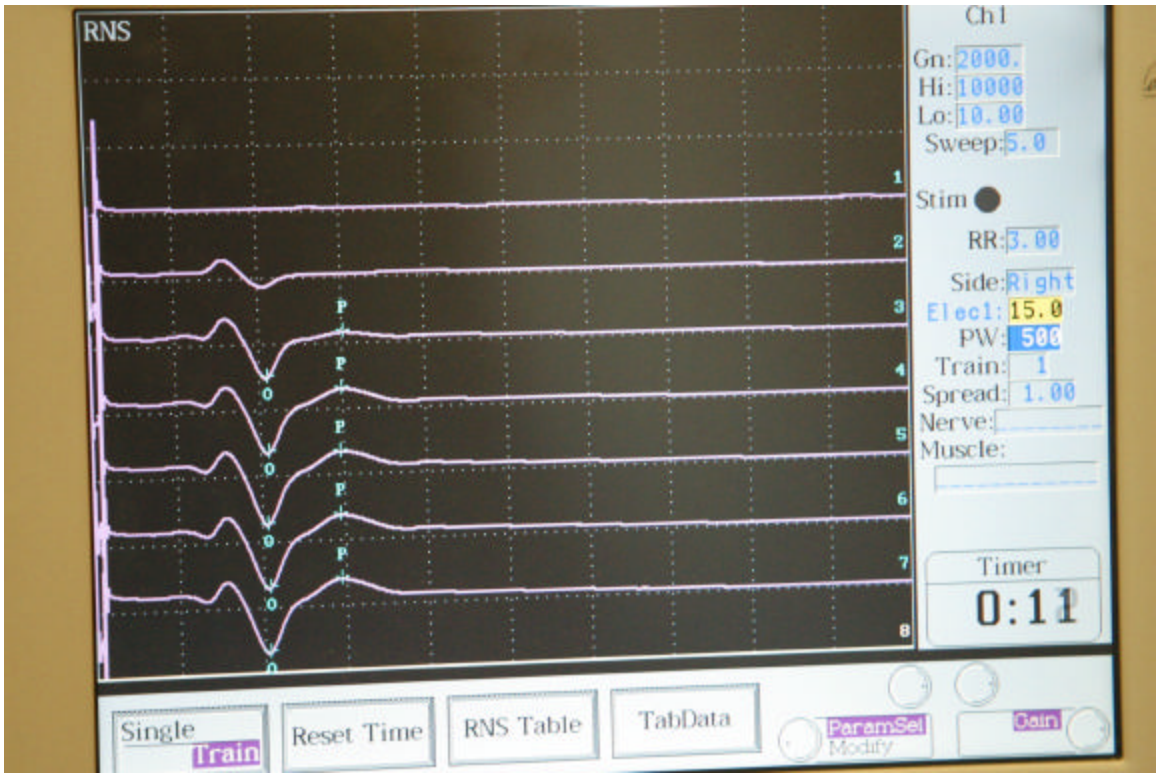

Figure 2- Computer display of H reflex recording

Muscle Stiffness- Muscle stiffness was measured by placing the subject in the seated position with the right leg at 90° at the hip and knee while passively extending the lower leg through a 60° arc. A belt around the ankle attached to a Sutter CPM 2000 produced a constant movement of 5° per second. The force of resistance from the subject's muscle was measured with a Westin 1971 panel meter.

Blood Flow- *Skin blood flow* was measured by a laser Doppler flow meter produced by Moor Instruments, Inc. The laser Doppler flow meter is a freestanding device that produces a beam of red laser light that scans a portion of the body. The device sits on a stand approximately 2 ft away from the patient. While the patient was prone, the device rapidly scanned the body and to produce a picture of the blood flow to the skin. This device is completely non-invasive and has no physical contact with the body.

Arm blood flow- Limb blood flow was calculated by Whitney volume plethysmography. This technique used a bracelet that contains a strain gage to measure limb volume. A venous occlusion cuff (40 mmHg) was inflated for 5 sec and deflated for 7 sec on the upper arm. An arterial occlusion cuff was fastened around the wrists and inflated to 200 mmHg. Changes in limb volume during the first 2 sec after inflation are proportional to limb blood flow and were recorded to assess the circulation through the entire arm. This technique has been described previously (Petrofsky et al. 1976).

Pulsatel Skin Blood Flow- Continuous measurements of pulse pressure in the skin and muscle were measured optically with a Hertzman photoelectric plethysmograph. The plethysmograph consists of either a small plastic ring that containing a light source and photocell for skin measurements or is in a 22-gauge needle for muscle measurements. The light source focused low intensity white light into the skin and the photocell recorded the beam that is instantly reflected back from the tissue. By amplifying this signal electronically from the photocell, a Pulsatel output is recorded which is proportional to the pulse flow in the skin under the light. This technique has been described previously (Petrofsky 1979).

Cardiac Output- Cardiac output was measured by impedance plethysmography. This technique involves placing 4 electrodes on the body, one each on the neck, on the top of the chest, on the abdomen and on the thigh. These electrodes pass a minute electrical current through the outside electrodes and from the inside electrodes electrical impedance was measured and cardiac output was calculated and displayed. The current was less than 1 milliamp at a frequency of 50,000 Hz (Figure 3).

Blood Pressure- Blood pressure was measured by auscultation of the inactive limb with a sphygmomanometer. The systolic blood pressure was determined as the first sound as the pressure was reduced in the cuff and the diastolic was identified as the change from a sharp to a muffled sound. The cuff was deflated at 3 mmHg/sec as per the American Heart Association Standard.

Heart Rate- Heart rate was measured with the impedance plethysmograph as described above. Heart rate was assessed from measuring the number of heart beats over a 10 sec period and multiplying by 6.

Cycle ergometer- Subjects cycled on land on a stationary cycle ergometer at 0 Kp and a speed of 50 rpm for 15 min.

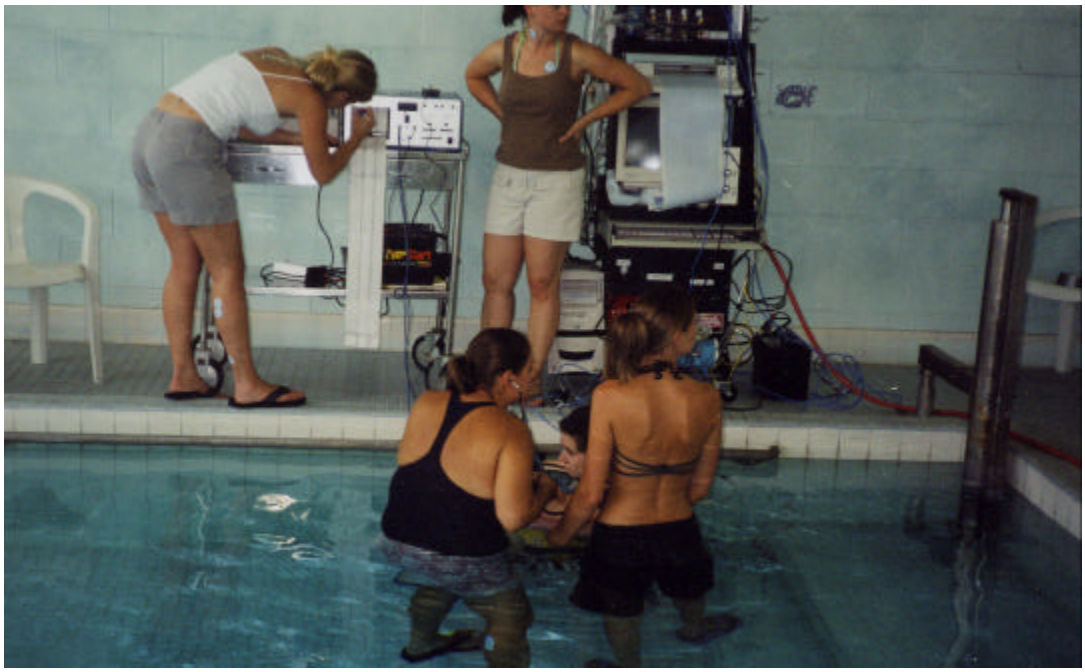

Figure 3- Subject immersed in water with electrodes attached for measuring stroke volume and cardiac output.

Figure 4- Subject during immersion

Procedures

Four series of experiments were conducted. In the first series, the relationship between skin and muscle blood flow and bath temperature was assessed. Because probes were inserted into the muscles, no movement was allowed to protect the subjects from damage to soft tissue due to potential probe movement. The other three series included the effects of passive immersion, exercise during pool immersion and exercise alone on motor neuron excitability and the cardiovascular system.

Series 1- During the first series of experiments, the relationship between muscle temperature, muscle blood flow, and skin blood flow was assessed in 5 subjects during immersion in a water bath at 36°C °C. At the onset of immersion at 5, 10, 15, 20, 25 and 30 min after immersion, muscle temperatures and skin blood flow (Herztman plethysmography) and total limb blood flow (Whitney Plethysmography) were measured. The Hertzman flows in muscles were assessed by inserting the needle tip approximately ½ the distance between the skin and the bone.

Series 2- The purpose of the 2nd series of experiments was to assess the effects of light exercise alone (an intensity equivalent to the exercise in the pool) on skin blood flow, muscle relaxation as assessed though H-reflexes, muscle stiffness, and circulation to the skin. Subjects rested quietly in a thermally neutral room, during which time the blood flow over the gastrocnemius muscles was measured by the laser Doppler flow meter. Next, H-reflex was measured with the subject in the prone position, as described under methods, to measure motor neuron excitability. Finally, with the subject in the seated position the leg was passively moved through a 60° range of motion and the force

generated at the 45° point was measured. EMG was also measured above the quadriceps muscle and hamstrings during extension of the leg to assess any muscle activity that may have been present with the subject at rest or during extension. Subject's then exercised on a bicycle ergometer for 15 min at 0 Kp, at approximately 50-60 rpm. After the 15 min exercise period pre-experimental measurements were repeated.

Series 3- In this series of experiments the effect of 30 minutes of only passive immersion of the body in a 36 deg C pool on muscle stiffness, skin blood flow and the cardiovascular system was examined. During a rest period prior to the experiments, subjects rested in a thermally neutral room (22-23°C) and blood pressure, heart rate, cardiac output, H-reflex activity, and muscle stiffness were measured. EMG was measured during passive movement of the limb to assess muscle tone. Blood flow to the skin was measured over the heads of the gastrocnemius muscle with a laser Doppler flow meter. The subjects were then placed in a 36°C pool for 30 min. During the time in the pool, cardiac output, heart rate and blood pressure were recorded every 5 min. At 30 min, the pre-experimental measurements were repeated. (Figure 4)

Series 4- The same parameters as series 3 experiments were examined except that light exercise was accomplished in the hydrotherapy pool. During the 30 min in the pool, cardiac output, blood pressure, and heart rate were recorded at 5 and 10 min. During the 10-25 min interval, subjects engaged in kicking exercises. Cardiac output, blood pressure, and heart rate were recorded post exercise. After the 30 min period the pre-experimental measurements were repeated.

Results

Tables 2, 3, 4, and 5 and figures 5 and 6 show the results of the 4 series of experiment.

Series 1

Figure 5 and 6 depict the results of the first series of experiments. Figure 5 shows that the resting muscle temperatures for the subjects averaged approximately 30.8 ±1.3°C. During the immersion period, temperature rapidly increased from the initial muscle temperatures toward that of the bath. For example, after 4 min of immersion deep muscle temperature increased from 30°C to 33°C. By the 12th minute of immersion the deep muscle temperature was equal to the pool temperature.

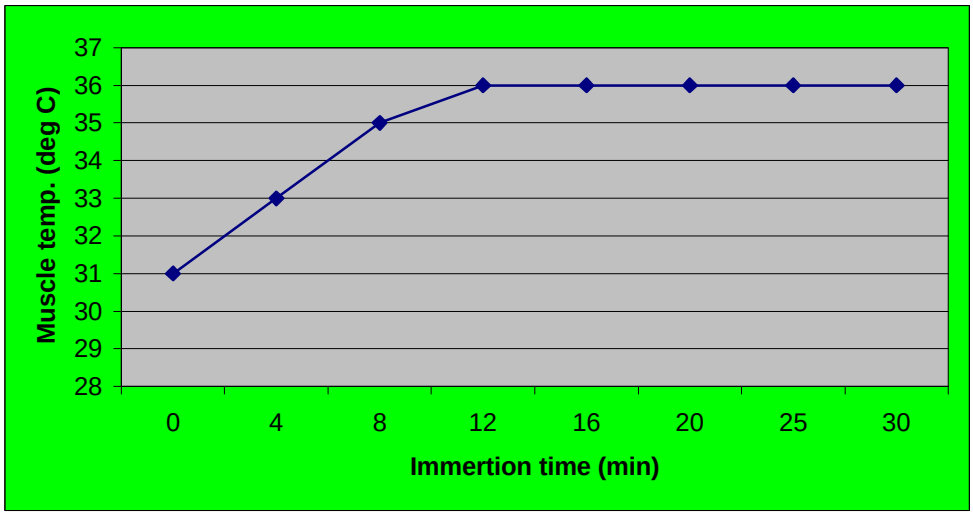

Figure 5- Deep muscle temperature after immersion in water at 34°C and 37°C

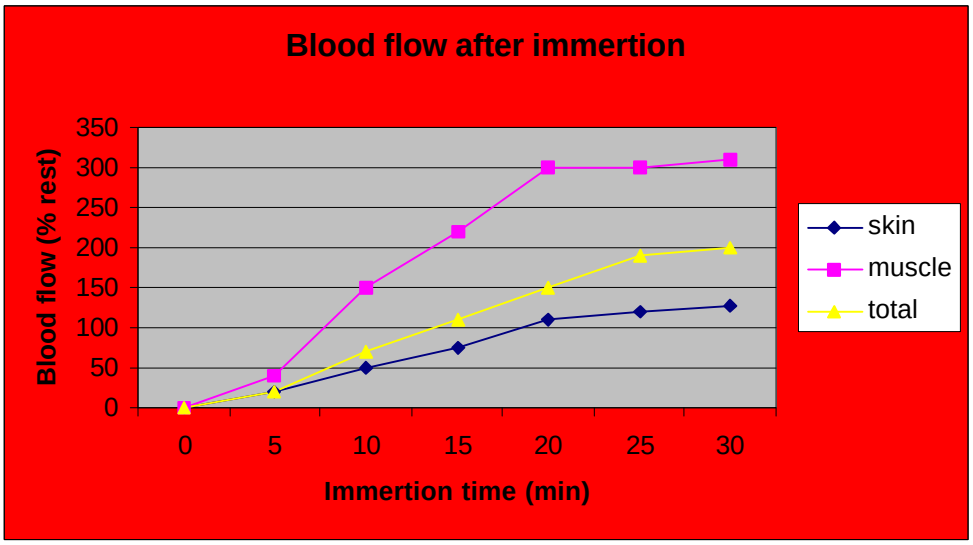

Figure 6- Muscle and skin blood flow after immersion in a bath at 36°C

On a separate day in another experiment, blood flow was measured in skin and muscle throughout immersion in a 36°C water bath. Total flows were measured by Whitney strain gauge plethysmography. As such, flows were in cc/100 g tissue/min. In contrast, flows measured by the Hertzman flow meters were relative flows. These flows increase or decrease proportionally to changes in circulation in the skin and could not be calibrated in absolute cc/100 g tissue. Therefore, for simplicity of presentation in the

graph, the resting flows prior to immersion were used to normalize flows during exposure. For example, a blood flow of 200% at rest after immersion would indicate a tripling of blood flow over the normal resting flows. As shown in figure 6, total flow increased by approximately 200% from rest to the end of the exposure to heat. Flows increased rapidly initially, such that after 15 min flows were 110% of the initial flows, and then increased more slowly over the next 15 min to 200% in excess of the original flows. Muscle blood flow increased to just over 300% over the original resting flow. This increase rapidly progressed for the first 20 min then remained steady for the last 10 min. Skin blood flow increased rapidly for the first 20 min to 111% over the original resting flow and then increased just slightly for the next 10 min to a final figure of 128 % over the original resting flow.

Series 2, 3, and 4

Muscle stiffness and EMG

Table 2 summarizes the average results of muscle stiffness and EMG activity above the quadriceps muscle for the 5 subjects. Table 2 illustrates that with resting exposure to a 36°C water bath, the average force to move the leg to an angle of 45° through a 60° arc was 0.82 ±0.14 kg before immersion and 0.63 ±0.12 kg after immersion.

Table 2- Muscle Stiffness and EMG Data

MUSCLE STIFFNESS EMG DATA SUMMARY

		POOL REST		POOL EXERCISE		BIKE	
		PRE	POST	PRE	POST	PRE	POST
FORCE	MEAN	0.822	0.632	0.808	0.73	0.652	0.634
(KG)	SD	0.14	0.12	0.131	0.135	0.035	0.04
EMG	MEAN	2.5	0.8	2.4	.7	3	2.5
(%MX)	SD	0.54	0.89	0.8	0.67	0.35	0.68

These differences from pre to post immersion were significant ($p<0.05$). In contrast, while the force required to move the lower leg was reduced a small amount pre and post immersion with exercise in the pool and before and after bicycling on a cycle ergometer, these differences were not statistically significant. For example, the amount of force to move the leg in 5 subjects averaged 0.65 ±0.04 kg before bicycle ergometry, and 0.65 ±0.04 kg post cycle ergometry. Certainly, some of the resistance to movement may be due to reflex activity from muscle as exemplifies by the low level EMG activity seen before hydrotherapy as shown in Table 2. EMG activity during movement after warming, but not after exercise without warm water immersion was reduced significantly. ($p <0.05$).

H-reflex data was similar to the muscle stiffness data. Table 3 shows the height of the H wave, M wave, H-M ratios and latency in all 3 series of experiments. H and M waves changed under all experimental conditions; therefore, as described previously, to properly analyze H-reflex the H-M ratio was used.

Table 3- H Reflex Data

H REFLEX DATA- SUMMARY

H	M	Latency	H/M		t test pre post
pre pool	19.3	38.5	25.3	1.41	<0.05
SD	8.1	35.2	13.6	1.35	
post pool	11.4	4.74	24.95	0.53	
SD	4.7	31.5	15.04	0.447	
		exercise			t test pre post
pre pool	24.3	25.3	19.2	1.25	>0.05
SD	16.9	22.3	8.2	0.99	
post pool	23.3	29.1	18.9	1	
SD	12.9	13.7	8.05	0.937	
		bike alone			t test pre post
pre bike	16	25.8	16.5	0.877	>0.05
SD	9.02	7.55	6.29	0.494	
post bike	16.47	34.9	15.4	0.77	
SD	8.35	23.89	4.28	0.77	

Passive immersion in the pool at 36°C caused a significant reduction in the H-M ratio in the 5 subjects who participated in series 2, 3, and 4. For instance, before pool immersion the average H-M ratio was 1.41 ±1.35, whereas after 30 min of passive immersion in the pool the H-M ratio was reduced to 0.53 ±0.45. Exercise in the pool as an intervention during passive heating also reduced the H-M ratio as shown in table 3. The H-M ratio went from 1.25 ±0.99 to 1±0.937 with exercise; however, these differences were not statistically significant. The differences on the bike alone before and after bicycling at room temperatures, which again showed a downward direction from 0.88±0.494 to 0.77±0.77, were not statistically significant. Therefore, the only

significant relaxation in the alpha motor neuron pool was found in passive immersion alone. Along with these changes in the neuromuscular system, the results showed significant changes in the cardiovascular system as well.

Cardiovascular system

The results of the cardiovascular studies are shown in table 4. Table 4 shows cardiovascular data at rest after 15, 25 and 30 min of pool immersion for both passive exposure to heating in the pool and exposure with the intervention of exercise. As can be seen from this table, with passive immersion in the pool stroke volume increased from 36.7 ±8.6 ml/beat to 52.75 ±6.6 ml/beat, and the heart rate under these same conditions increased from 77.5 ±5 beats/min to 87.5± 9.6 beats/min.

Table 4- Cardiovascular Data

CARDIOVASCULAR DATA

Pool Rest				
	stroke volume (cc)	heart rate(b/min)	cardiac output(l)	BP(mmHg)
rest	**36.7**	**77.5**	**2.877**	117/76
15 min	**51.7**	**85**	**4.42**	115/69
25 min	**51.9**	**87**	**4.51**	111/67
30 min	**52.7**	**87.5**	**4.8**	110/66

Pool Exercise				
	stroke volume(cc)	heart rate(b/min)	cardiac output(l)	BP (mmHg)
rest	**37.8**	**87.5**	**3.3**	117/76
15 min	**49**	**87.5**	**4.275**	***during exercise

25 min	**66.7**	**91**	**5.83**	112/74
30 min	**62.5**	**100**	**5.65**	111/71

The cardiac output (the product of stroke volume and heart rate) increased significantly from the beginning to the end of the immersion period. Cardiac output increased from 2.87 ±0.807 L/min to 4.77 ±0.91 L/min at the end of the 30 min passive immersion period. During exercise in the pool, the average stroke volume at rest was 37.75 ±3.3 ml and increased to 62.5 ±3.31 ml per beat at the end of the exercise period. Heart rate increased from 87.5 ±5 beats/min to 100 ±7.07 beats/min at the end of the 30 min period with exercise. Cardiac output increased from 3.3 ±0.42 ml/beat at rest to 5.65 ±1.04 L/min at the end of the 30 min period. The difference between stroke volume after 25 or 30 min, and heart rate and cardiac output, when comparing the exercise exposure to the passive exposure, were significantly higher ($p < 0.05$). While stroke volume, heart rate and cardiac output all were higher with exercise in the pool, there was no significant difference in blood pressure at 15, 25 or 30 min after immersion in the pool with the subject at rest or with exercise. While the general trend was for the blood pressure to be slightly higher during exercise in the pool, there was no statistical difference in this data.

Table 5 shows the blood flow to the skin under all 3 experimental conditions. Flows are shown as raw flux data and percent increases from the Doppler flow meter. Comparing the flows before and after immersion in the pool during passive resting, flux increased from 109 ±23 to 174 ±59 flux units. This was an increase of 173%. For the 5 subjects that participated in this series of experiments, the increase was significant ($p<0.05$). Exercise in the pool caused an increase from baseline values of 98 ±21 to 232 ±128 flux units.

Table 5- Blood flow during immersion

BLOOD FLOW TO SKIN

	rest pool		exercise- pool		bike	
	pre	post	pre	post	pre	post
mean	109	174	98	232	98	114
sd	23	59	21	128	3.4	41
% increase		173		231		113

This increase of 231% was a significant increase comparing pre to post exercise and immersion data and was significantly higher than that of the same subjects who were simply resting in the pool for 30 min. In contrast to these large increases in flow seen with immersion, bicycling for 15 min resulted in only slight increases in flows. Flows increased by 113% as indicated by an increase from 98 ±3.4 to 114 ±41 flux units. The change in flow seen in the pre to post exercise bouts was not statistically significant. Therefore, blood flow significantly increased during passive immersion in the pool and exercise in the pool, whereas bicycling had no significant affect on skin blood flow.

Discussion

Hydrotherapy has been a mode of medical treatment for thousands of years. For example in early Greece, hydrotherapy was used for purifying rituals (Diamandopoulos et al 1997). It was used in England as long as two thousand years ago (Moss 2000). Recently it has been used for pediatrics (Dumas and Francesconi 2001), paraplegia (Gass and Gass 2001), for burns (Acikel et al 2001), and to modulate cellular immunity (Blazickova et al 2000). It has been recommended to increase the circulation in patients with diabetes (Cox 2000, Bernstein 2000). It has been used in the treatment of low back injuries (Konlian 1999). Yet, little evidence has been provided as to why hydrotherapy benefits either the cardiovascular system or the neuromuscular system. Most of these studies have provided little hard evidence and are no more that anecdotal in nature. Therefore, the present investigation attempted to look at two different factors allegedly affected by hydrotherapy, the first muscle relaxation and the second the effect of hydrotherapy on the cardiovascular system.

The present investigation showed a reduction in the force it took to passively move the leg after warm water hydrotherapy. Previous studies have shown an increase in stretch and H reflexes of the lower leg in man during whole body cooling (Oksa et al 2000). Here the converse is true. The reduction in reflex activity and stiffness of the muscle associated with warmer temperatures could have several possible mechanisms. There might be changes in the muscle itself, changes in excitability of the alpha motor neuron pool mediated by muscle spindles or central mediation by increased inhibitory outflow from the brain associated with whole body heating.

Many studies have pointed to whole body relaxation when patients were passively immersed in a warm water bath (Cammu et al 1994, Campion 1990). The overall effect of warming the body and input from thermal sensors in the skin may cause an increase in central inhibition into the upper motor neuron pool which might therefore lower H reflexes but not directly alter muscle stiffness nor the contractile mechanism in muscle. While this remains a possibility in the present studies, the present investigation does not lend itself to determining the influence of central inhibition on the reduction in the H reflex seen here.

However, studies in man have shown a reduction in the T reflex associated with cooling and an increase with heating (Bell and Lehmann 1987). The mechanism for the reduction in the H reflex with heating has been attributed to a reduction in secondary spindle activity associated with the heating process (Michalski and Seguin 1975). Whereas primary spindle afferents seem to be unaffected by muscle temperature, secondary spindle afferents show a reduction in activity associated with heating. This reduction in activity could lower the excitability of the alpha motor neuron pool. More telling may be the effect of light exercise. When exercise was accomplished in the pool, the H reflex was only reduced by a small amount. Further, exercise out of the pool, had no effect on the H reflex at all when comparing the reflex before and after the exercise.

During exercise, muscle spindles are active and when muscles are activated both the alpha and gamma systems discharge. Both primary and secondary afferents are also active from the spindles (Petersen et al 1999). Central and peripheral control fo alpha motor neuron excitability is so dynamic during exercise that H reflexes are modulated in various phases of the step cycle from very enhanced to completely inhibited

all in one cycle during walking (Petersen et al 1999). This same type of response is seen during cycling on a bicycle ergometer (Zehr et al 2001). It would seem likely, then, that exercise may in fact maintain potentiate muscle spindle activity whereas warm water hydrotherapy would reduce spindle output. Therefore, exercise in a therapeutic pool, because of the activity of the muscle spindles, will keep spindles active and thereby negate some of the effect of the warm water exposure alone on muscle spindle activity. In the present investigation, subjects exercised with light kicking in the middle of the exposure in the hydrotherapy pool. Therefore, a period of five minutes elapsed from the end of exercise to the point of when H reflexes were measured after immersion. For this reason, if H reflexes were measured at the end of the exercise in the warm water, the results may have been very similar to the light exercise alone on the cycle ergometer outside of the pool. That is, there may not have been any reduction in H reflex activity.

But H reflexes alone may not have been the only factor influencing the resistance to passive movement seen in these studies. Certainly, the effect of temperature on muscle is the opposite of the results seen in the present series of experiments.

Warming muscle increases muscle relaxation (Wang and Kawai 2001), ATP utilization and the length of attachment and strength of attachment of cross bridges (Hilber et al 2001). Muscle ATPase activity is highly related to muscle temperature. The Q10 of skeletal muscle has been shown to vary between 3 and 10 in various studies (Hilber et al 2001). Therefore, the actual reduction in H reflex activity seen here would probably have had a much greater effect on muscle relaxation if not for the increase metabolism in skeletal muscle causing an increase in muscle stiffness associated with actomyosin ATPase activity. The change in muscle temperature here, was almost 6

degrees centigrade, therefore, muscle metabolism, even conservatively, would double or triple associated with warming of muscle.

Whatever the mechanism, clearly passive light exercise and light exercise in a pool had a very minimal effect on muscle relaxation. To maximize muscle relaxation simple passive heating or passive pool emersion is the best mechanism.

But the present study also looked at the cardiovascular responses to immersion and immersion with light exercise. As seen in the results of these studies the increase in blood flow to the limb is minimal associated with passive heating. As stated above, although the Q10 may be as high as 9.7 in skeletal muscle, other studies show that the Q10 of the skin may be as low as 1.3 (Wang and Kawai 2001). Therefore, metabolism in skin and many tissues in the limb can be virtually unaffected by changing temperature even 5 or 6 degrees centigrade. For this reason it is not surprising that resting blood flows are only increased approximately 3 fold associated with passive heating. Exercise can cause an increase in flows of as much as 100 fold (Petrofsky 1982). Since the Q10 of skin is much lower than skeletal muscle it is not surprising, then, that these studies showed most of the increase in flow not being to the skin, but being to the muscle itself. Hydrotherapy then, may not have a very large impact on skin flows when using hydrotherapy for wound healing or to increase circulation to the skin and the body. However, hydrotherapy does have a more significant impact in increasing blood flow to muscle and tendons and would therefore work well for helping healing muscle tears and other soft tissue injuries.

Increases in cardiac output and reduction in blood pressure associated with hydrotherapy and skin blood flow were only modest. Any potential training effects on

the heart or cardiovascular system with the mild change in cardiac output and blood pressure seen here will be minimal.

In summary, there is evidence that hydrotherapy alone can cause clinically significant increases in circulation through skeletal muscle and small increases through skin as well as causing an increase in muscle relaxation. However, if muscle relaxation is the goal of the therapy, light exercise should not be attempted. If increases in circulation is the goal of therapy, then light exercise in the pool potentiates the small increase in skin and muscle circulation and in fact should be recommended as a therapeutic modality. More studies need to be conducted looking at various types and intensities of exercise as well as other water temperatures to thoroughly understand the optimal use of hydrotherapy in clinical medicine.

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Table 1- General Characteristics of Subjects- all data shown +/- the SD

	Age (years)	Height(cm)	Weight (kg)	number
Males	24+/-2.4	173+/-6.4	84.2+/-16.1	5
Females	25+/-2.1	164.5+/-3.8	66.5+/-14.3	5
Group	24.3+/-2.3	169 +/- 6.2	75.1+/- 18.9	10

Figure Legends

Figure 1- Electrode position for measuring the H reflex

Figure 2- Computer display of H reflex recording

Figure 3- Subject immersed in water with electrodes attached for measuring stroke volume and cardiac output.

Figure 4- Subject during immersion

Figure 5- Deep muscle temperature after immersion in water at 34°C and 37°C

Figure 6- Muscle and skin blood flow after immersion in a bath at 36°C

Table 1 General Characteristics of Subjects

Subject	Age (years)	Height (cm)	Weight (Kg)
1	26	161.925	52.272
2	27	161.29	60.909
3	23	162.56	67.272
4	25	170.18	90.227
5	22	166.37	61.591
mean	25	164.465	66.4542
sd	2.073644	3.756711	14.3296

Table 2- Muscle Stiffness and EMG Data

MUSCLE STIFFNESS EMG DATA SUMMARY

		POOL REST		POOL EXERCISE		BIKE	
		PRE	POST	PRE	POST	PRE	POST
FORCE	MEAN	0.822	0.632	0.808	0.73	0.652	0.634
(KG)	SD	0.14	0.12	0.131	0.135	0.035	0.04
EMG	MEAN	2.5	0.8	2.4	.7	3	2.5
(%MX)	SD	0.54	0.89	0.8	0.67	0.35	0.68

Table 3- H Reflex Data

H REFLEX DATA- SUMMARY

	H	M	Latency	H/M	t test pre post
pre pool	19.3	38.5	25.3	1.41	<0.05
SD	8.1	35.2	13.6	1.35	
post pool	11.4	4.74	24.95	0.53	
SD	4.7	31.5	15.04	0.447	
			exercise		t test pre post
pre pool	24.3	25.3	19.2	1.25	>0.05
SD	16.9	22.3	8.2	0.99	
post pool	23.3	29.1	18.9	1	
SD	12.9	13.7	8.05	0.937	
			bike alone		t test pre post
pre bike	16	25.8	16.5	0.877	>0.05
SD	9.02	7.55	6.29	0.494	
post bike	16.47	34.9	15.4	0.77	
SD	8.35	23.89	4.28	0.77	

Table 4- Cardiovascular Data

CARDIOVASCULAR DATA

Pool Rest

	stroke volume (cc)	heart rate(b/min)	cardiac output(l)	BP(mmHg)
rest	**36.7**	**77.5**	**2.877**	117/76
15 min	**51.7**	**85**	**4.42**	115/69
25 min	**51.9**	**87**	**4.51**	111/67
30 min	**52.7**	**87.5**	**4.8**	110/66

Pool Exercise

	stroke volume(cc)	heart rate(b/min)	cardiac output(l)	BP (mmHg)
rest	**37.8**	**87.5**	**3.3**	117/76
15 min	**49**	**87.5**	**4.275**	***during exercise
25 min	**66.7**	**91**	**5.83**	112/74
30 min	**62.5**	**100**	**5.65**	111/71

Table 5- Blood flow during immersion

BLOOD FLOW TO SKIN

	rest pool		exercise- pool		bike	
	pre	post	pre	post	pre	post
mean	109	174	98	232	98	114
sd	23	59	21	128	3.4	41
% increase		173		231		113