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PHYSICAL PREDICTORS OF LIMB VENOUS COMPLIANCE: A CORRELATIONAL
STUDY

by

Jeff Sojka

B.S., Southern Illinois University, 2012

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Science in Education

Department of Exercise Science
in the Graduate School
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A Research Paper Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Masters

in the field of Exercise Science

Approved by:

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Graduate School
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CHAPTER 1

INTRODUCTION

There has been extensive research demonstrating the effects of physical variables and different modes of exercise on arterial compliance. However, there has been much less attention focused on the venous vasculature and the physical and fitness variables that may affect how the veins comply with changes in orthostasis. Previous cross-sectional studies have found that venous compliance decreases with age (Monahan, Dinneno, Seals, & Halliwill, 2001; Tsutsui, Sagawa, Yamauchi, Endo, Yamazaki, & Shiraki, 2002; Hernandez & Franke, 2005; Lanne & Olsen, 1997), increases with improved fitness (Hernandez & Franke, 2004; Hernandez & Godar, 2009; Monahan et al., 2001), and may be different between men and women (Monahan & Ray, 2004; Meendering, Torgrimson, Houghton, Halliwill, & Minson, 2005; Linderberger & Lanne, 2007a).

The venous vasculature is a volume reservoir containing approximately 70% of our total blood volume and is designed to preserve flow of blood from the tissues to the heart during cardiovascular stress. Venous compliance is especially important to understand in that veins are 30-50 times more elastic than the arterial vasculature (Rowell, 1993). Venous compliance is represented by the relationship of venous volume and venous transmural pressure. The pressure-volume relationship is important in the maintenance of homeostasis through maintaining venous return, resulting in attenuated decreases in arterial blood pressure as a result of orthostatic stress (Halliwill, Minson, & Joyner, 1999; Rowell, 1993). This means that veins could hold roughly 70% of total blood volume at any time which can lead to conflicts with

blood pressure and the maintenance of homeostasis. A number of different variables such as age, fitness level, and sex have been shown to influence venous compliance.

Age

Aging has been associated with a decrease in venous compliance. Everyone will go through the ageing process and its impact on blood flow may be positive or negative, which is dependent on health status. Aging, as suggested by Moodithaya and Avadhany (2011), reflects a diminished cardiovascular sympathetic modulation. Similarly, the recovery of heart rate after exercise becomes blunted with age as a result of sluggish cardiac vagal response to adjust the cardiac activity (Moodithaya & Avadhany, 2011). Monahan, Dinneno, Seals, and Halliwill (2001), demonstrated that calf venous compliance was about 40% lower in elderly subjects. Tsutsui, Sagawa, Yamauchi, Endo, Yamazaki, and Shiraki (2002) and Hernandez & Franke (2005) showed similar results. Tsutsui et al. (2002) observed that leg compliance was lower with an increase in blood volume in older adults in comparison to young participants, when lower body negative pressure (LBNP) was applied to invoke changes in limb volume. The older participants in the study had lower stroke volume (SV). These results suggest that the reduction in venous return to the heart was less in magnitude in older participants during LBNP (Tsutsui et al., 2002). Hernandez & Franke (2005) reported an increase in heart rate (HR) among older adults compared with younger participants in response to similar orthostatic stress placed upon both groups. This increase in HR suggests there is a decrease in venous return to the heart, which coincides with a decreased venous compliance. Lanne and Olsen (1997) reported a decreased capacitance response with aging when the lower body negative pressure method was used to induce blood pooling to the lower extremities. This suggests there is a decline in the

sympathetic reflex response, resulting in a decrease in venous compliance. However, the effects of aging on venous compliance can be mitigated somewhat through participating in physical activity.

Fitness

High aerobic fitness is associated with an increased venous compliance. Hernandez and Franke (2004) found that there is an increased venous compliance with fitness in both young and older participants and a decreased venous compliance, overall, with age. This suggests that higher fitness levels are associated with an increase in venous compliance, even as one ages. Hernandez & Godar (2009) found that total calf volume increase was greater in endurance trained females than their normally active counterparts. Hernandez & Godar (2009) also observed that endurance trained females had higher calf venous compliance and greater capillary filtration than average fit females. Similar, Hernandez & Franke (2005) reported a 20-30% increase in venous compliance following a 6 month endurance training program in older and younger adults. Monahan et al. (2001) found that endurance training could improve venous compliance by 70-120% and can attenuate the effects of age-associated reductions in venous compliance. They found that endurance trained older males have 30% greater compliance than young sedentary males (Monahan et al, 2001). These findings suggest that aging may cause a decrease in venous compliance but can be attenuated by greater fitness levels along with exercise, specifically endurance training.

Sex

Sex is another variable that has been found to have an effect on venous compliance. Monahan & Ray (2004) showed that young males have a 48% greater calf venous compliance in comparison to females of similar age. Meendering, Torgrimson, Houghton, Halliwill, & Minson (2005) had similar results in that females had exhibited a 19-26% lower venous compliance than males. This study was observed during the different phases of the female menstrual cycle and there were no differences found on the effects of these phases on venous compliance. There was also no compliance differences found in participants using oral contraceptives between high and low hormone phases. These studies suggest that males have greater venous compliance and fluctuating hormone levels is not the underlying factor to this result. Lindenberger & Lanne (2007a) found that females had lower venous compliance at lower pressures than males but when increasing transmural pressures were applied, there were no differences observed. It is important to note that of the studies just mentioned, only Lindenberger and Lanne (2007a) used LBNP to invoke limb venous changes while the other studies all used venous occlusion plethysmography. Interestingly, Hernandez & Godar (2009) found that females exhibit higher capillary filtration levels than males. When comparing fitness levels between sexes, endurance trained males have consistently been found to show higher venous compliance than their sedentary peers (Hernandez & Franke, 2005; Monahan et al., 2001). Hernandez & Godar (2009) found that endurance trained females had 40% higher venous compliance than females of average fitness. When comparing females of above average fitness to males of average fitness, they found that females had higher venous compliance (Hernandez & Godar, 2009). Hernandez & Franke (2009) found no observable differences in venous compliance in older adults. These studies suggest that males tend to

have greater venous compliance when compared to their female counterparts. It also suggests that endurance trained participants have greater venous compliance than participants of average fitness and sedentary individuals, between both sexes alike.

All previous investigations of venous compliance in humans have involved small numbers of participants involved in group comparisons. Little research has investigated correlations between body size, age, fitness, and sex in a large population. Therefore, the purpose of this study was to determine the relationships between physical variables and how they affect the dependent variable of venous compliance using a correlational method of research. It was hypothesized that aging, higher body fat percentage, and BMI will be associated with a lower venous compliance. A 2nd hypothesis was that a higher fitness level will be correlated with a higher venous compliance.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Over the past century, there has been dramatic decreases in physical activity observed within today's society. The reasoning behind this shift is multifocal; however, this change from being a physically active society to a sedentary society has made it more difficult for individuals to maintain a healthy lifestyle and cardiovascular system through exercise and participation in physical activity. A sedentary lifestyle is commonly associated with an increase of cardiovascular disease, hypertension, and aortic and arterial stiffness within this population. As a result of this association, there has been a greater occurrence of myocardial infarctions and stroke among the sedentary population (Blacher, Guerin, Pannier, Marchais, Safar, & London, 1999; Laurent, Boutouyrie, Asmar, Gautier, Laloux, Guize, Ducimetiere, & Benetos, 2001). Previous research has mostly focused on the changes in arterial adaptations to exercise and physical conditions while studies on venous vasculature have not been as common.

Venous compliance and arterial compliance differ in a number of ways, but the elastic components of the vessels are of particular relevance to this research. Veins are approximately 30 to 50 times more compliant than arteries, which allows venous vasculature to hold roughly 70% of total blood volume that falls below the heart within the cardiovascular system upon standing (Hernandez & Godar, 2009). With this shift of blood volume occurring due to gravity, there is a decrease in central blood volume, which places a stress on the cardiovascular system to maintain blood flow throughout the body. To counteract this shift in blood volume,

sympathetic modulation and skeletal muscle pump action increases in succession of blood pressure maintenance and homeostasis (Rothe, 1983; Rowell, 1993).

Venous compliance is represented by the relationship of venous volume and venous transmural pressure (Rowell, 1993). There are many variables, such as age, fitness level, and sex, which can alter or change how the veins comply. As we age, venous compliance has been shown to decrease (Monahan et al., 2001; Tsutsui et al., 2002; Hernandez & Franke, 2005). Both males and females with higher fitness levels have shown to have increased venous compliance in both younger and older participants (Hernandez & Franke, 2004). Hernandez & Godar (2009) found that total calf volume increase was greater in endurance trained females than their normally active counterparts. Sex has been suggested to have an effect on venous compliance at different ages (Hernandez & Franke, 2005; Meendeering et al., 2005; Monahan & Ray, 2004).

Therefore, the purpose of this review of literature is to examine previous studies on the topic of venous compliance and the effects that physical variables of age, fitness level, and sex have on how veins comply with pressure.

EVALUATION OF VENOUS COMPLIANCE IN HUMANS

The evaluation of venous compliance is dependent upon a number of different variables to consider in determining venous compliance. Rowell (1993) had stated that as pressure increases, compliance tends to decrease as a result of the increase in blood volume in the veins. The initial increase of blood volume is called the capacitance response. This response is defined as the relationship between transmural pressure and total volume within the vasculature (Rowell 1993). The capacitance response is a quick response that is generally completed within

three minutes (Rowell 1993). Capillary filtration is determined from the filtration slope that is typically completed between three and eight minutes (Lindenberger & Lanne 2007a; Schnizer, Klatt, Baeker, & Rieckert, 1978). With capillary filtration, there is a gradual and continuous rise in leg volume that demonstrates the net transcapillary fluid transfer from the blood to the tissue (Lanne & Olsen, 1997).

Previous studies have examined lower limb venous compliance through the methods of venous occlusion plethysmography. This method uses strain gauges to measure the changes that occur within the calf muscle. This provides information of the change in limb volume from before, during, and after pressure has been applied. This pressure is used to measure the overall venous compliance of the calf. This consists placing a venous collecting cuff around the thigh that is proximal to the knee. The strain gauge is wrapped around the calf at its maximal circumference. With the limb elevated above the heart, pressure is increased proximal to the knee, which results in an increase of calf volume. Most previous studies using to this methodology has commonly inflated the collection cuff to 60mmHg until there was a rise in intervenous pressure, similar to the levels of the collection cuff pressure. Following this rise of intervenous pressure will be a decrease in pressure, at which the rate and time of the cuff being deflated, as well as at what point the measurements are being recorded at, are dependent upon the researcher's discretion and liking. Previous researchers have slightly modified the protocols that were set forth from past studies in order to build a better protocol for future research.

Robison and Wilson (1968) measured compliance by inflating the pressure of the collection cuff to 60mmHg until intervenous pressure rose to similar levels of pressure. After

intervenous pressure had risen, the collection cuff was decreased at a pace of 1mmHg/s until 0mmHg. Data consisting of blood volume was recorded. However, questions arose about this methodology used because the study assumes that resting pressure is equal to 0mmHg.

Halliwill et al (1999) confirmed that intervenous pressure is said to be below 10mmHg and suggested that pressure ranges of 10mmHg to 60mmHg should only be analyzed.

Buckey, Lane, Plath, Gaffney, Baisch, & Blomqvist (1992) slightly modified previous protocols by using multiple collecting cuff pressures. The collecting cuff was inflated to 20, 40, 50, and 60 mmHg in that order and pressure was decreased by two minute intervals. There was a shift to higher blood volumes in the pressure-volume relationship that was related to the lack of extended rest periods between each interval. This methodology is time consuming and is also difficult to make observations of compliance because of the lack of time between each interval. Melchoir and Fortney (1993) took a similar methodological approach as Buckey et al. (1992) but decreased cuff pressure to exactly 0mmHg following each pressure interval. This methodology assumes that an observer can determine when intervenous pressure has reached steady state, in which Halliwill et al. (1999) found that this is not possible.

These issues and questions about these methodological approaches led Halliwill et al. (1999) to create a new noninvasive approach for measuring whole-limb venous compliance. It consisted of a 4-minute period of cuff inflation to 60mmHg which was followed by a decrease in pressure of 1mmHg/s over a 60 second time frame. This method allowed for faster compliance measurements while allowing researchers to observe venous compliance measurements in smaller time frames. This is advantageous in that it mitigates the process of testing the effects of sympathetic components on compliance.

Skogg, Zachrisson, Lindenberger, Ekman, Exerman, & Lanne (2015) took a similar approach as Halliwill et al. (1999). Skogg used a strain-gauge plethysmography approach in which a strain-gauge was applied at the maximal calf circumference and there was an increase of pressure to 60mmHg within 1-2 seconds. After 4 or 8 minutes of venous stasis, the pressure was reduced at a rate of 1mmHg/s, using a custom-built device that enables a linear pressure decrease (Zachrisson, Lindenberger, Hallman, Ekman, Neider, & Lanne, 2011). Not only does this allow for faster venous compliance measurements but for more accurate measurements while being able to observe these measurements in smaller time frames.

To go along with the more modern methodologically presented by Halliwill et al. (1999) and Skogg et al. (2015), lower body negative pressure (LBNP) chambers were used as a method to induce blood pooling in the lower limbs (Hernandez & Franke 2005; Lindenberger & Lanne 2007a; Lindenberger & Lanne 2007b; Monahan & Ray 2004). This blood pooling in the lower limb acts as if the human body is standing and the venous components can be measured in determining venous compliance. However, there are some concerns with this approach. LBNP has been shown to elicit an increase in a sympathetic response, but evidence does not show parallel similarities on the effect this sympathetic response has on limb venous compliance (Halliwill et al. 1999; Monahan & Ray 2004). Another issue is that LBNP is designed to stimulate the orthostatic stress that is placed on humans when standing but without the actual position change of the human.

THE EFFECTS OF PHYSICAL VARIABLES ON VENOUS COMPLIANCE

Age

As the aging process occurs, the cardiovascular system experiences a number of changes that cannot be prevented in which occurs at different rates for each individual. From previous research, it has been shown that there is an increase in arterial stiffness and a decrease in arterial elasticity associated with ageing. Decreases in arterial compliance has been associated with cardiovascular diseases, in particular, coronary heart disease (Bertovic, Waddell, Gatzka, Cameron, Dart, & Bronwyn, 1999) as well as hypertension (Van Merode, Hick, Hoeks, Rahn, & Reneman, 1988). As these changes occur, this leads to an increased afterload on the left ventricle, which in turn increases systolic blood pressure. This results in left ventricular hypertrophy.

Many of the previous studies have found that a decrease in venous compliance occurs as one ages (Hernandez & Franke, 2004; Hernandez, Karandikar, & Franke, 2005; Monahan et al., 2001). Lanne and Olsen (1997) reported a decreased capacitance response with aging when using the LBNP method to induce blood pooling. This suggests that there is a declining sympathetic reflex response that occurs with ageing, which would result in lower limb venous compliance. This decrease in capacitance response can be a possible explanation for decreased venous compliance among older adults (Lanne & Olsen, 1997).

Even though it is found that venous compliance decreases with age, there is evidence that suggests a decline in venous compliance can be mitigated through exercise and physical activity. This was shown by Monahan et al. (2001), which found that calf venous compliance was reduced overall between young and old men, but was better preserved in endurance-trained men in comparison to sedentary men. In another study, there was evidence that showed venous compliance improvements following a 6-month endurance training program

(Hernandez & Franke, 2005). These studies suggest the importance of implementing a physical activity program to increase or maintain optimal venous compliance of the cardiovascular system, even as one ages.

Fitness Levels

Previous research has shown that higher levels of fitness is associated with higher levels of venous compliance (Convertino, Montgomery, & Greenleaf, 1984; Louisy, Jouanin, & Guezennec, 1997; Olsen & Lanne, 1998; Monahan et al., 2001). There is evidence that exercise could not only improve venous compliance by 70 to 120% but could reduce the age-associated decline of venous compliance (Monahan et al., 2001). They found that endurance-trained older males have greater compliance improvements than young sedentary males. This suggests that venous compliance can be improved or attenuated by engaging in an endurance training program.

Convertino, Doerr, and Stein (1989) found an inverse relationship between venous compliance of the leg and the size of the muscle itself following 30 days of microgravity stimulation. The calf muscle often decreased from the stimulation while there was an increase in venous compliance. This suggests a decrease in muscle mass can result to an increase of venous compliance. However, Kawano, Tanimoto, Yamamoto, Gando, Sanada, Tabeta, Highuchi, & Miyachi (2010) has found that an increase in muscle mass had no significant effect on venous compliance. Kawano et al. (2010) has suggested muscle mass is not responsible for changes in venous compliance but rather venous volume has shown to have a significant positive relationship in association with venous compliance. Kawano et al. (2010) has also

found that forearm venous compliance increased as muscle mass increased which further contrasts the findings of Convertino, Doerr, and Stein.

Using a low-intensity blood-flow-restricted (BFR) exercise protocol, Iida, Kurano, Takano, Kubota, Morita, Meguro, Sato, Abe, Yamazaki, Uno, Takenake, Hirose, & Nakajima (2007) found that there was an increase in venous compliance following a 6-week training program in untrained older adult female participants, while there was no change in the control group. Iida also found a significant increase in calf girth measurements which further contrasts Convertino et al. (1989) original suggestion that there is an inverse relationship between muscle mass and venous compliance.

Sex

Previous research has found a difference between male's venous compliance in comparison to the female's venous compliance. Monahan and Ray (2004) found that young females have a 48% lower calf venous compliance than their age-matched male counterparts. Even though males have shown greater venous compliance, the LBNP resulted in males possibly showing a decrease in venous compliance while females did not. Monahan and Ray (2004) have also found similar results in the decline of capacitance response from the LBNP being applied. This suggests that capacitance response can be observed with no changes of venous compliance. Meendering et al. (2005) found similar venous compliance results in that females exhibit 19-26% lower compliance than males. This study was observed during phases of the female menstrual cycle, which demonstrated no differences in compliance. This suggests that hormonal levels during menstrual cycling do not have an effect on venous compliance. Linderberger and Lanne (2007a) found that with increased transmural pressure, there was no

differences of venous compliance between males and females. However, it was found that females have a lower compliance with lower pressures. The results of this study suggest that with a reduction in male's venous compliance with increased pressure, that there are no differences found at lower pressures being applied. Also, Linderberger and Lanne (2007a) found that differences between males and females in compliance vanished when capillary filtration was not a factor when calculating venous compliance. Similar to Linderberger and Lanne (2007a), Hernandez and Godar (2009) found that females exhibit higher capillary filtration levels than males. These two studies suggest that capillary filtration is the common variable between observed sex differences pertaining to venous compliance.

Meendering et al. (2005) and Monahan and Ray (2004) have previously found that untrained females have a lower venous compliance in comparison to untrained male counterparts. In a similar study to Hernandez and Franke (2005), Hernandez and Godar (2009) were interested in the female response between endurance-trained females than females of average fitness. The results included the endurance-trained females having a 40% higher compliance, a higher net capillary filtration, and higher capacitance volumes than females of average fitness. They also found that above average females, in comparison to males of average fitness, that females had higher venous compliance. This contrasts Hernandez and Godar (2009) study, which suggests capillary filtration is not the only factor for sex differences pertaining to venous compliance. Hernandez and Godar (2009) have also found, in contrast to Meendering et al. (2005) and Monahan and Ray (2004), that there was no sex differences of venous compliance in young females and males of a similar age group. Hernandez and Franke

(2005) have found that there were no differences in older adults on venous compliance between both sexes.

CONCLUSION

It is of equal importance to study venous vasculature the same as arterial vasculature, with veins being responsible for holding 70% of total blood volume when the human body is standing. Venous compliance allows for the maintenance of blood pressure and homeostasis as the body moves during physical activity (Rothe, 1983; Rowell 1993). There are number of variables that influence venous compliance. As the human body ages, it has been shown that venous compliance decreases (Lanne & Olsen, 1997; Monahan et al., 2001). Fitness levels is another variable in that evidence has suggested the decline in venous compliance from ageing can be mitigated following a physical activity program (Hernandez & Franke, 2005; Hernandez & Godar, 2009; Monahan et al., 2001). The final variable that has previously been observed is the effects of sex differences on venous compliance. Evidence has found that females have shown lower venous compliance at a young age compared to males (Meendering et al., 2005; Monahan & Ray, 2004) but sex differences amongst older adults on venous compliance suggests otherwise, in that there are no sex differences in older adults (Hernandez & Franke, 2005).

CHAPTER 3

METHODS

Participants

Participants consisted of 173 adults (men and women) between the ages of 18-75. All participants were healthy based on medical history, a resting blood pressure <140/90 mmHg, no reported use of tobacco, body fat <30%, free of any diagnosed cardiovascular disease, and not taking any cardiovascular medication. Participants were placed into different groups that were relevant to the participant's age and fitness levels. Participants refrained from any exercise, alcohol, or caffeine ingestion for 12 hours, and food consumption at least 1 hour before being tested. Younger female participants were tested in the follicular phase (3-10 days from the first day of menstruation) of their menstrual cycle, all reported regular menstrual cycles, and post-menopausal women were not on hormone replacement therapy. Written informed consents was obtained according to practices established by the Southern Illinois University Human Subjects Committee.

Experimental Design

Data collection was performed at a room temperature between 23-25° Celsius. Participants reported to the laboratory on two separate occasions. The first meeting was to assess anthropometric status and to determine VO₂peak. Resting blood pressure was assessed manually using a sphygmomanometer by placing the pressure cuff on the upper arm. Height (cm) and weight (kg) were assessed using a stadiometer and balance scale. Body composition was determined by using a Lange skinfold caliper. All participants underwent a maximal graded

exercise test (BRUCE protocol) to determine their fitness status. Peak oxygen uptake (VO_2peak) estimates were obtained for all the participants by using the time to termination of the stress test as the criteria. Participant heart rate was monitored by using a Polar Heart Rate monitor throughout the fitness test. The second visit occurred 24-48 hours after the first visit and included determination of limb venous compliance. Participants were instructed to report to the laboratory prior to any exercise or caffeine consumption.

Venous Compliance

To determine venous compliance of participants, the studies used similar methods of venous occlusion plethysmography that were presented by Halliwill et al. (1999) and Skogg et al. (2014). While lying in the supine position with the right leg elevated above heart level, participants were supported at the ankle and thigh. Calf volume was calculated from the mean of four girth measurements obtained equidistantly between the medial malleolus and the tibial plateau and from one calf segment length. Changes in limb volume were measured noninvasively using strain gauge plethysmography at the maximal calf circumference. A venous collecting cuff was placed approximately 5 cm proximal to the right knee and inflated to 60mmHg for 8 minutes. Reductions in pressure occurred at a rate of 5mmHg/5 seconds, over one minute, until pressure was at 0mmHg.

Analysis

To determine venous compliance, pressure-volume curves were generated from the pressure-volume relationship as pressure was decreased from 60mmHg to 10mmHg, by means of 5mmHg/5 seconds. Comparisons were made using the quadratic regression model $[(\Delta\text{limb}$

volume) = $\beta_0 + \beta_1 * (\text{cuff pressure}) + \beta_2 * (\text{cuff pressure})^2$], where Δ is the difference between the limb volume at a given cuff pressure and the resting, preinflation, cuff volume, β_0 is the intercept, and β_1 and β_2 are slope components for each participant. Anthropometric and venous compliance data included between-participant classifications for age and training status. Anthropometric and fitness variables were compared to venous compliance at 20mmHg using a linear stepwise multiple regression analysis. Statistical significance was set at $p < 0.05$.

CHAPTER 4

RESULTS

Physical Characteristics & Lower Limb Venous Compliance

Physical characteristics and lower limb venous compliance of participants are summarized in Table 1. Weight, height, BMI, body fat (%), diastolic blood pressure, and resting heart rate were significantly associated with lower limb venous compliance. There were no significant influences on lower limb venous compliance from age, fitness, or systolic blood pressure.

Table 1. Participant Characteristics

<u>Variables</u>	<u>Mean</u>	<u>Standard Deviation</u>
Age (yr)	27	14.5
Weight (kg)*	74.47	15.12
Height (cm)*	173.79	9.37
BMI*	24.53	4.00
Body Fat (%)*	18.17	7.30
VO ₂ (ml/kg/min)	49.26	18.18
Calf Volume (ml)	549.56	130.45
Systolic BP (mmHg)	118	10.5
Diastolic BP (mmHg)*	74	9.7
Resting Heart Rate (bpm)*	67	10.2
Capillary Filtration (ml)	1.0474	1.7496
Capacitance (ml)	1.7861	0.7515
Δ Calf Volume (ml)	2.8335	2.0252
β ₀	1.1474	3.7121
β ₁	0.0998	0.1176
β ₂	-0.0129	0.1581
Compliance @20mmHG	-0.2846	6.3709

N = 173 (male = 74, female = 99). BMI, body mass index; VO₂, volume of oxygen consumed; BP, blood pressure; Δ Calf Volume = $\beta_0 + \beta_1 * (\text{cuff pressure}) + \beta_2 * (\text{cuff pressure})^2$; *p<0.05.

Physical Variables & Lower Limb Venous Compliance

Table 2. Weight & Body Fat (%)

Variables	R	R Square	Adjusted R Square	Std. Error of the Estimate	Significance
Weight (kg)	0.240	0.058	0.050	0.74434	0.009
Body Fat (%)	0.354	0.125	0.110	0.72036	0.000

N = 117 (male = 46, female = 71).

Table 2 displays the physical characteristics of weight and body fat percentage on lower limb venous compliance using 117 participants that met requirements. The reason for the difference in participants used is because 117 participants met all criteria pertaining to the data set, while the others that were not used did have missing criteria within the data set. Missing criteria of these data sets included weight, height, body fat, BMI, VO_2^{peak} , and RHR and were exclusionary criteria in the determination of the most significant variable associations with venous compliance. Using the Stepwise Regression equation, weight and body fat percentage showed the strongest relationship to limb venous compliance among physical characteristics of participants. However, figures 1 and 2 show the relationship is miniscule, in nature. Figures 3 and 4 show that there were no differences observed between age and fitness levels on calf venous compliance levels. This suggests that age and fitness levels are not the underlying factor as to how the venous vasculature system responds to pressure.

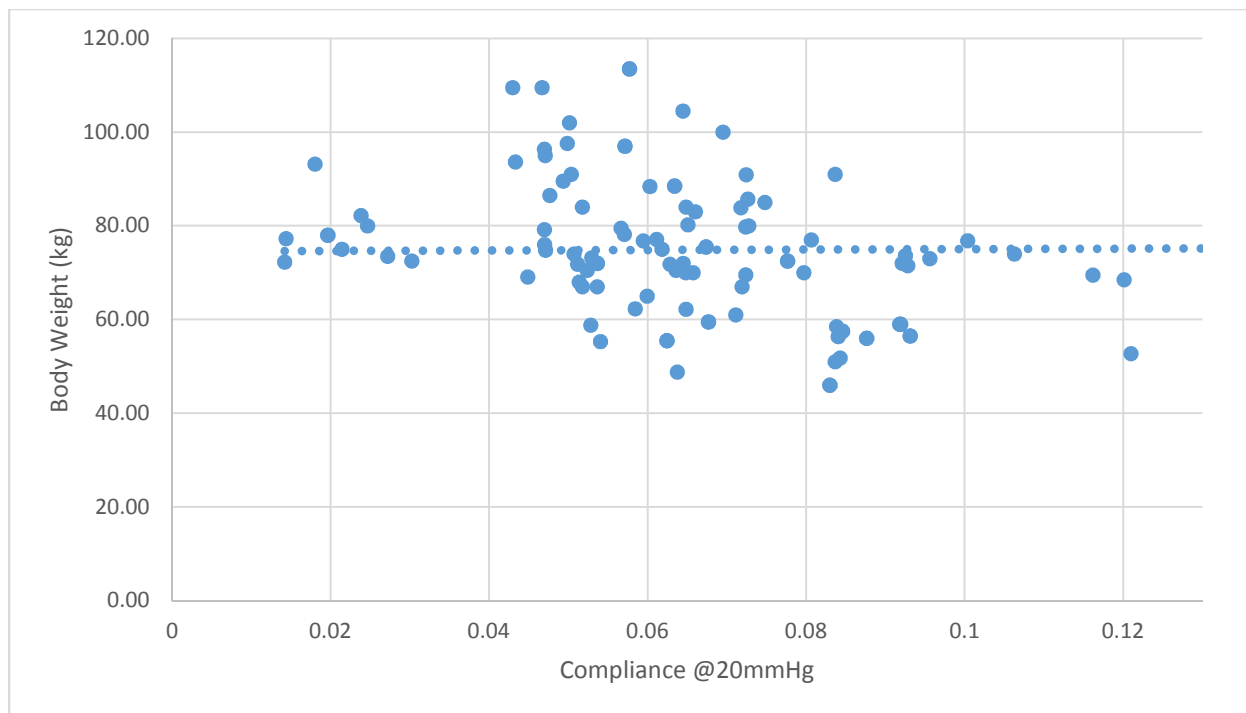


Figure 1. Venous compliance @20mmHg & body weight.

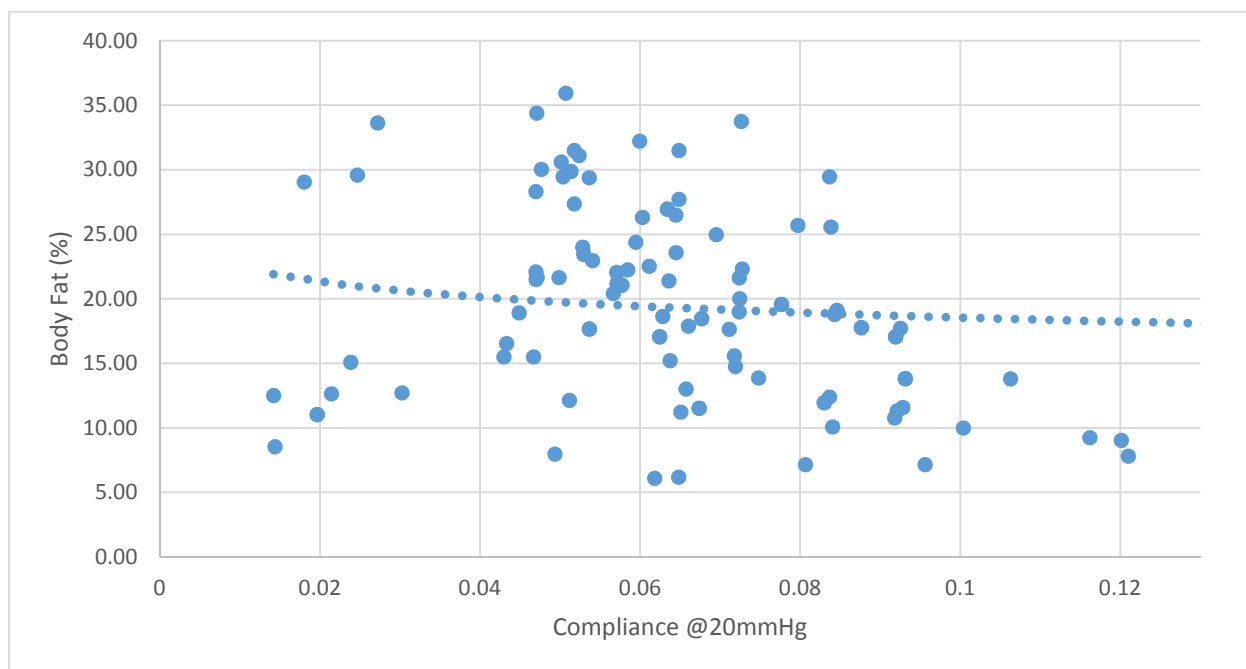


Figure 2. Venous compliance @20mmHg & body fat (%).

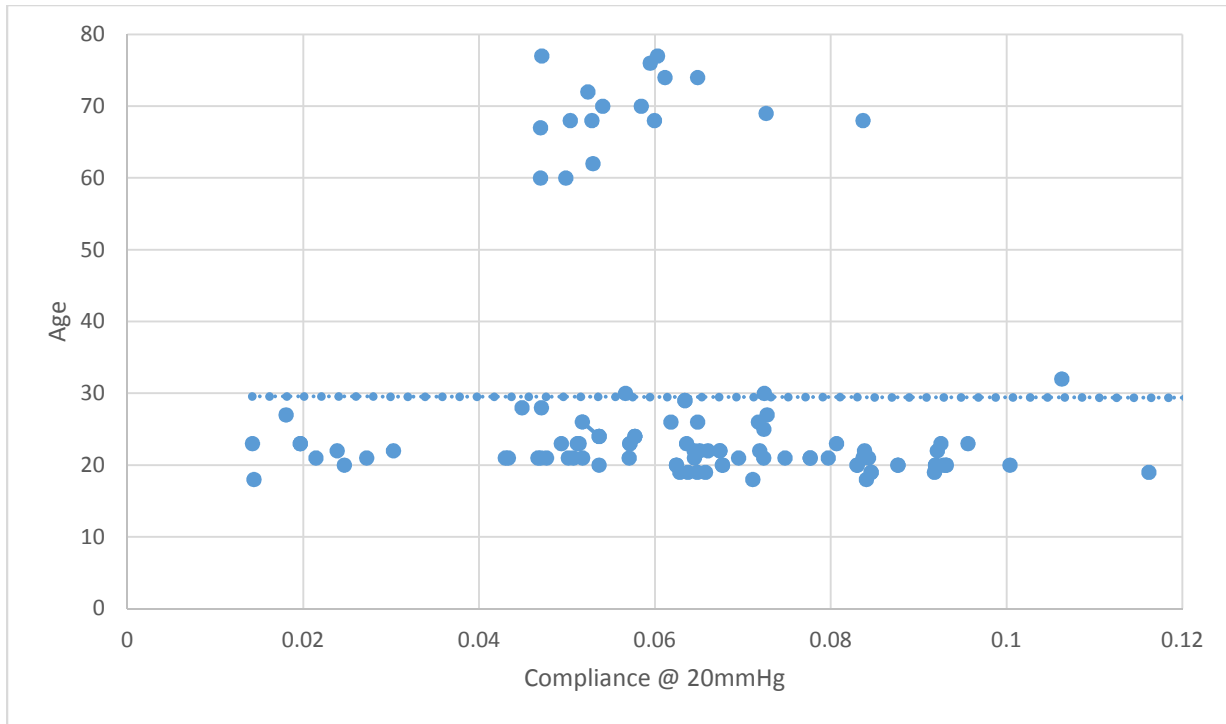


Figure 3. Venous compliance @20mmHg & Age.

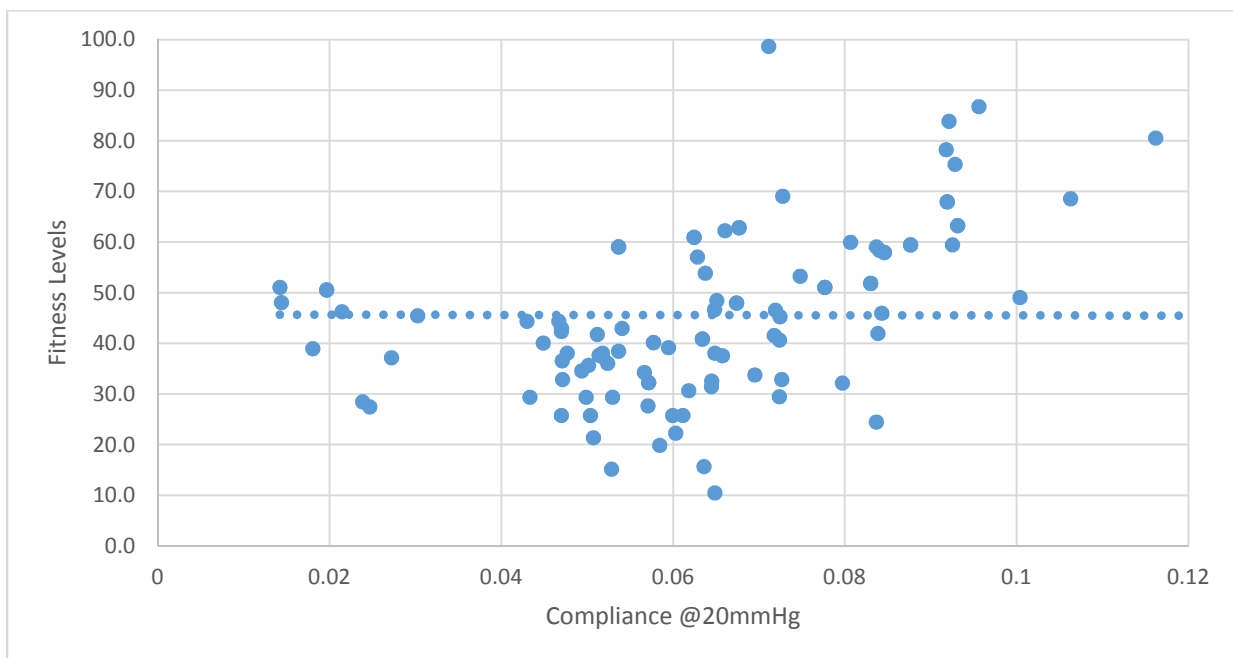


Figure 4. Venous compliance @20mmHg & fitness levels.

CHAPTER 5

DISCUSSION

There has been limited research on the effects of physical variables on venous compliance. This present study uses regression equations in determining correlations and relationships between physical variables and venous compliance. The purpose of this study was to determine the relationships between physical variables and how they affect the dependent variable of venous compliance using a correlational method of research. It was hypothesized that increased age, higher body fat percentage and BMI would be associated with lower venous compliance. A 2nd hypothesis was that a higher value of VO₂peak would be associated with a higher venous compliance. The findings of this study supported our first hypothesis, as body fat percentage and BMI showed a negative significant difference on the effect of venous compliance. However, a higher value of VO₂peak did not have a significant relationship to venous compliance.

Previous research has shown that as one ages, there is a decreased response in venous compliance (Hernandez & Franke, 2004; Hernandez, Karandikar, & Franke, 2005; Monahan et al., 2001). Lanne and Olsen (1997) found that there is a decline in capacitance response as one goes through the ageing process. To determine this, Lanne and Olsen (1997) used the LBNP method to induce blood pooling, which is a way to induce blood flow to the lower limbs to a volume similar to a human standing but without the action of standing. These studies suggest that there is a correlation between ageing and a decreasing sympathetic reflex response, which results in a decline in lower limb venous compliance. In the present study, there were no

significant relationships found between ageing and the effects it has on venous compliance. A possible explanation of this finding is the data sets used for this study were taken from previous studies and had a vast gap pertaining to age ranges. Young adults were no older than 33 years of age while older adults consisted of 60 years of age or more (Figure 3).

With the findings of this study exhibiting an increase in blood volume to the lower extremities among older adults, it has been suggested that this effect can be mitigated through physical activity and exercise (Convertino, Montgomery, & Greenleaf, 1984; Louisy, Jouanin, & Guezennec, 1997; Olsen & Lanne, 1998; Monahan et al., 2001). According to Monahan et al. (2001) exercise has been found to improve venous compliance by 70% to 120% and could reduce age-associated decline of venous compliance. Monahan found that endurance-trained older males have greater compliance than young sedentary males. This suggests that venous compliance can be improved or attenuated by participating in regular physical activity. In this present study, there were no significant difference on the effects of fitness levels on venous compliance. A possible explanation of this finding is the fitness level differences among the participants, with some being considered as above-average and others being considered average or below-average.

Using the Stepwise Regression Equation, the two physical variables that had the strongest relationship to venous compliance were weight and body fat percentage. Previous research has not focused on these two variables but rather has focused on age, fitness levels, and sex differences, which can play a role in weight and body fat percentage. The findings from the present study suggest that higher body fat results in a decrease of venous compliance, creating an inverse relationship between them. This relationship could have masked the

relationship between fitness and venous compliance and is an interesting finding given that all participants in the study had less than 30% body fat. If we are seeing a significant relationship in this data set, it will be very important to examine venous compliance in obese individuals.

Limitations

There are several issues to consider when interpreting these results. A limitation of this study is that the population of participants consisted mostly of Caucasian individuals. This makes it difficult to generalize the findings to other races.

Venous occlusion plethysmography is a measure of whole limb volume changes. The 8 minute collecting cuff pressure application should have been long enough to make sure that the pressure in the veins matched the pressure in the cuff.

Finally, there was an immense gap in age ranges within the data set. Middle-aged adults were not included but only younger and older adults.

Conclusion

In conclusion, the effects of fitness levels and age on venous compliance were not observed in this study even though there was a tendency of these variables on venous compliance similar to previous research. These trends included ageing effects in which results in a decrease in venous compliance. Along with that, fitness levels that are above-average will demonstrate greater compliance than those who are less fit which has been found in previous research. Higher body fat, higher body mass, and higher BMI were significantly related to lower venous compliance. These physical variables should be further researched in order to determine a possible inverted relationship between body composition and venous compliance.

This is of great importance because venous properties are closely associated with cardiovascular health.

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