The effect of a cooling cuff and moist ice pack on radial artery blood flow and lumen diameter

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ABSTRACT

Background:

When a soft tissue injury occurs the blood vessels and surrounding tissue are damaged leading to haemorrhaging and inflammation. Cryotherapy (cold therapy) is generally acknowledged as the preferable treatment by manual therapists during this immediate post-traumatic period of an injury. Cryotherapy has been shown to result in vasoconstriction decreasing the rate of blood flow which has a favourable effect on inflammation and pain. The commercially available cooling cuff is a relatively new cryotherapy modality offering a mechanism of cooling that does not require freezing and is easy to use. The polymer granules within the cooling cuff are activated by emersion in water therefore freezing is not required making the cooling cuff readily available compared to more traditional forms of cryotherapy.

Aim:

The aim of this study was to determine the effect of a moist ice pack and a commercially available cooling cuff radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) after 15 minutes of application.

Method:

This study was a pre-test post-test design utilising 43 asymptomatic participants that were randomly allocated to one of two groups. Each group either received a standard moist ice pack or a commercially available cooling cuff, placed on the ventral surface of the participants forearm, over the radial artery, for a duration of 15 minutes. Measurements were taken with a Doppler ultrasound to determine radial artery blood flow and lumen diameter, prior to the intervention and 15 minutes after the cryotherapy application. Data analysis was performed using IBM SPSS VERSION 20 (IBM Corp. Released 2010.IBM SPSS Statistics for Windows, Version 19.0. Armonk, New York: IBM Corp.). Statistical significance was set at a $p< 0.05$ level. Intra-group and inter-group comparisons were measured using repeated measures ANOVA testing.

Results:

Both the moist ice pack and commercially available cooling cuff resulted in a significant decrease in radial artery blood flow ($p < 0.001$) after 15 minutes of application with no significant changes being observed in radial artery diameter

Conclusions:

The commercially available cooling cuff resulted in a similar effect on radial artery blood flow and lumen diameter as moist ice, indicating that the commercially available cooling cuff may be utilised in the acute phase of an injury to alter blood flow.

Key words: cryotherapy, moist ice pack, radial artery blood flow, lumen diameter

DEDICATION

This dissertation is dedicated to:

God, for keeping me, guiding me and giving me the strength to get to where I am today.

Philippians 4:13: I can do all things through Christ who strengthens me.

and to

my parents (David and Beverley), who have sacrificed so much and for being my anchor. Thank you for always believing in me and giving me the opportunity to get to where I am today.

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TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS:

ADH	-	Anti-diuretic hormone
ANOVA	-	Analysis of variance
ATP	-	Adenosine Triphosphate
BMI	-	Body Mass Index
CO	-	Cardiac output
$cm.s^{-1}$	-	Centimetres per second
°C	-	Degrees Celsius
DOMS	-	Delayed onset muscle soreness
FDA	-	Federal drug administration
Ha	-	Alternate hypothesis
H_O	-	Null hypothesis
MHz	-	Megahertz
n	-	Sample size
mm	-	Millimetres
NCV	-	Nerve conduction velocity
OA	-	Osteoarthritis
PTO	-	Pain tolerance
THO	-	Total hip arthroplasty
TPR	-	Total peripheral resistance
SV	-	Stroke volume
viz.	-	Namely
SD	-	Standard deviation
3-D	-	Three-dimensional
>	-	Greater than

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

According to Stedman's Medical Dictionary (2006), cryotherapy is defined as the use of a cold application to treat a disease. Cryotherapy is utilised as the first line of treatment for numerous types of post-traumatic injuries (Smith et al., 1993). The prevalence of such injuries reported in an American population were 44% for sprains and strains, 25% for fractures with 40% of people reporting low back in the previous three months (Jacobs, 2011). Cryotherapy has also been shown to be effective in increasing pain threshold and reducing inflammation, when applied instantly or within seven days post-injury (Bleakley *et al*., 2004). There are many different techniques and ways of applying cryotherapy (Michlovitz, 1996; Cameron, 1999); however, some are more effective than others. The most commonly used by practitioners are traditional, ice packs and cooling gels (Topp *et al.,* 2011). The majority of chiropractors in the United States of America (92.6%) were shown to utilise cryotherapy techniques as anon-adjustive therapy in their treatment protocols (Christensen, 1996).

Cryotherapy is proposed to bring about its effects in three ways: firstly, by increasing a patient's pain threshold (Hubbard *et al.*, 2004), through decreasing the temperature of their peripheral nerves, thus decreasing the conduction velocities in motor (conveys impulses to muscles or glands) and sensory nerves (conveys impulses from receptors to the brain) (Bleakley *et al*., 2004). Secondly, by reducing the patient's metabolic rate (Hubbard *et al.*, 2004), which decreases the demand for oxygen in the damaged hypoxic tissue, and in so doing allows the tissue to have a greater duration of survival (Hubbard *et al.*, 2004). The third way is through vasoconstriction and a reduction in blood flow (Fiscus *et al.*, 2005; Topp, *et al.*, 2009). Vasoconstriction is mediated through various mechanisms which lead to a reduction in localised blood flow to the area, and results in a reduced rate of inflammation that decreases the amount of swelling to the area (Cameron, 1999).

If ice is applied to the body for extended periods of time, greater than 30 minutes (McKeag and Moeller, 1993), the ice may lead to cooling below critical temperatures (15C°) (Meeusen and Lievens, 1986) which may lead to soft tissue damage and a non-desired negative effect (increasing the level of pain and delaying full recovery at the site of injury) (Taylor, 2008). Not all cryotherapy techniques utilise the same methods of application and this has been shown to alter their effect. Schaser *et al*. (2007) demonstrated that a cryotherapy technique utilising percutaneous perfusion with 0.9% sodium chloride (8C°) used on a male rat with a soft tissue injury for a prolonged cooling (six hours) was highly beneficial in the treatment of injury.

The commercially available cooling cuff has recently been developed by a German based manufacturer. The manufacturer claims that the commercially available cooling cuff delivers cooling to the area of application, and in so doing reduces swelling and eases aches and pains (Sievers, 2006). The cooling cuff consists of polymer granules that are activated by placing the cuff in normal tap water, once activated the cuff can deliver cryotherapy, it does not require a freezer or ice. According to the manufacturer it does not lead to the 'hunting reaction' (a non-desired increase in blood flow), as the polymer granules inside the cuff allow cooling to occur through a natural evaporation mechanism, thereby allowing it to be applied for longer durations than ice (Sievers, 2006).There is a paucity of literature indicating the cooling cuffs effectiveness against more traditional forms of cryotherapy such as ice. Therefore, this study set out to determine the effect of the commercially available cooling cuff compared to a moist ice pack on radial artery blood flow and diameter within a time frame for ice application that was safe and shown to be effective.

1.2 AIM AND OBJECTIVES OF THE STUDY

This study aimed to determine the effect of a moist ice pack compared to a commercially available cooling cuff on radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm). The following were objectives of this study:

Objective One

To determine the baseline radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) before cryotherapy application.

Objective Two

To determine the effect of applying a moist ice pack to the ventral surface of the forearm on radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) after 15 minutes of application.

Objective Three

To determine the effect of applying a commercially available cooling cuff to the ventral surface of the forearm on radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) after 15 mins of application.

Objective Four

To compare the radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) of the moist ice pack group to that of the commercial cooling cuff group after 15 mins of application.

Objective Five

To document any adverse effects from the use of the commercially available cooling cuff.

1.3 HYPOTHESIS OF THE STUDY

The null hypothesis (H_O) stated there will be no statistically significant difference between the commercially available cooling cuff and moist ice pack groups after 15 mins in terms of radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm).

The alternate hypothesis (Ha) stated that the commercially available cooling cuff will show a statistically significant difference in terms of radial artery blood flow ($cm.s^{-1}$) and

radial artery lumen diameter (mm) when compared to the moist ice pack group after 15 mins.

1.4 LIMITATIONS

This study was conducted on an asymptomatic population to determine the physiological effect of the commercially available cooling cuff compared to ice, whereas cryotherapy methods are usually applied to symptomatic patients. Therefore due to the pathophysiology of a symptomatic patient, the generalizability of these results may be jeopardised.

The manufacturers of the commercially available cooling cuff encourage the use of the cooling cuff for periods longer than what is normally recommended for ice application. The manufacturers advertise that it can be utilised up to 24 hours (Sievers, 2006). This study was limited to testing the effect of the commercially available cooling cuff over a duration of 15 mins, which is considered an appropriate time frame for ice application (Michlovitz, 1996).

The researcher relied on the honesty of the participants in answering questions relating to their smoking status, alcohol consumption, or other stimulants or recreational drugs and / or their involvement in any strenuous physical activity 24 hours prior to participating in the research trial.

1.5 RATIONALE FOR THE STUDY

The commercially available cooling cuff is a novel product with limited independent research being conducted testing its effectiveness. The manufacturer claims that the commercially available cooling cuff delivers cooling to the area of application, and in so doing reduces swelling and eases aches and pains. The effects of the commercially available cooling cuff to induce similar changes to a more traditional form of

cryotherapy, such as ice, has not been investigated. This study aimed to compare the commercially available cooling cuff to a conventional moist ice pack to determine if evidence exists to support the use of the cooling cuff. If it can be demonstrated that the commercially available cooling cuff had a similar effect to ice application then practitioners, lay people and sportsmen and women could use the cooling cuff as an alternative treatment for soft tissue injury.

1.6 FLOW OF DISSERTATION

Chapter One introduced the back ground to the study, the aims and objectives, the hypothesis, limitations and rationale for the study. Chapter Two will present the review of the literature and this will be followed by Chapter Three which will detail the methodology utilised to carry out this study. Chapter Four presents the results of the statistical analysis and Chapter Five will discuss the results in relation to the existing literature. Chapter Six will conclude this study as well as highlight any recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Cold therapy, also known as cryotherapy is acknowledged as the preferable treatment by manual therapists in the immediate post-traumatic period of an athletic injury, viz. strains, sprains, contusions, fractures and inflammatory conditions (Smith *et al.*, 1993; Meeusen *et al.*, 1998; Jutte *et al*., 2001). Common methods of applying cryotherapy include ice packs, ice cubes, cold baths and cooling gels. When there has been an injury the blood vessels and surrounding tissue are damaged leading to haemorrhaging and inflammation (Todar, 2008). Cryotherapy has been shown to vasoconstrict blood vessels, which in turn decreases the rate of blood flow to the injured area, it also decreases local metabolism, and reduces nerve excitability (Schafer and Faye, 1990). Thereby effectively controlling pain, inflammation and oedema (Michlovitz, 1996; Cameron, 1999).

The anatomy of the radial artery and the factors that affect arterial blood flow and diameter will be discussed followed by methods of assessing blood flow and how cryotherapy works and the different types of cryotherapy techniques available.

2.2 DESCRIPTION AND STRUCTURE OF ARTERIES

Arteries are the blood vessels in the body that are responsible for the transportation of oxygenated blood (excluding pulmonary arteries) away from the heart and act as a means to deliver the oxygenated blood to the entire human body (Waugh and Grant, 2010). The arterial wall consists of three different layers viz. the tunica intima, tunica media and an outer most layer, the tunica adventitia, with each layer having its own characteristics. In addition, there are three types of arteries (elastic arteries, muscular arteries and arterioles) which are distinguished by their morphological characteristics dependent on their size and function (Waugh and Grant, 2010).

2.2.1 Elastic Arteries

Elastic arteries (Figure 1) are the largest type of arteries. These arteries contain a greater amount of elastic tissue and less smooth muscle making up the tunica media layer than the other two types of arteries. This allows the artery vessel wall to stretch following contractions by the heart and assist the body in maintaining systemic blood pressure (Moore and Agur, 2002; Waugh and Grant, 2010). The tunica intima is composed of flattened elongated endothelial cells with a polygonal appearance, arranged longitudinally to assist blood flow (Williams and Warwick, 1980; Standring, 2005). The tunica intima has a layer of internal elastic lamina resting on it, separating it from the tunica media. The tunica media is distinctly marked with layers of interlamellar muscle cells, elastin containing fenestrations, fine elastic fibres and collagen (Williams and Warwick, 1980; Standring, 2005). The adventitia of elastic arteries are made up of fibroblasts with slender projecting processes, lymph drainage vessels, mast cells and macrophages, bunches of nerves that encompass elastic fibres with associated collagen fibres (Williams and Warwick, 1980; Standring, 2005).

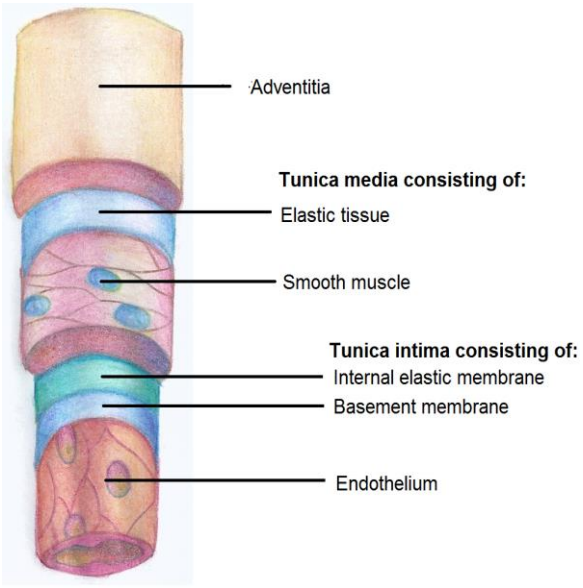

Figure 1: Layers of an artery wall (Fox, 2011)

2.2.2 Muscular Arteries

Muscular arteries are mainly composed of circular layered smooth muscle which forms part of the tunica media (Figure 1) (Moore and Agur, 2002). When the smooth muscle in the vessel contracts, the lumina (inner space in the artery where blood flows) of the vessel will narrow (constrict). Therefore, this vessel is responsible for regulating the blood flow to various parts of the body (Moore and Agur, 2002). The tunica intima is composed of a thin distinctive layer of internal elastic lamina, resting on a basement membrane and endothelium cell layer. The tunica adventitia is mainly composed of collagenous connective tissue. The external elastic lamina separates the tunica adventitia from the tunica media (Standring, 2005).

2.2.3 Arterioles and Capillaries

Arterioles (Figure 2) are the terminal arteries that end by interacting with the capillary network (Stedman, 2006). They are the smallest of the three vessels (elastic and muscular arteries), having a relatively narrow lumina, consisting of six or less concentric layers of smooth muscle cell layers in the tunica media. The main composition of arteriole walls is made up of the tunica media (Williams and Warwick, 1980; Moore and Agur, 2002; Stedman, 2006; Waugh and Grant, 2010). The lumen is surrounded by a thin, single layer of elongated endothelial cells (tunica intima), with a layer of patchy internal elastic lamina interposed between the tunica media (Williams and Warwick, 1980; Wheater *et al*., 1987). The adventitia can be equal in size to the media and contains a fine network of collagen fibres and interacts with the surrounding connective tissue (Williams and Warwick, 1980; Wheater *et al*., 1987). This vessel is mainly responsible for the degree of pressure within the arterial system, regulated by the tonus (firmness) of the smooth muscle cells within the arteriole wall (Moore and Agur, 2002; Waugh and Grant, 2010). Capillaries (Figure 3) consist of a thin layer of endothelium resting on an outer basement membrane layer.

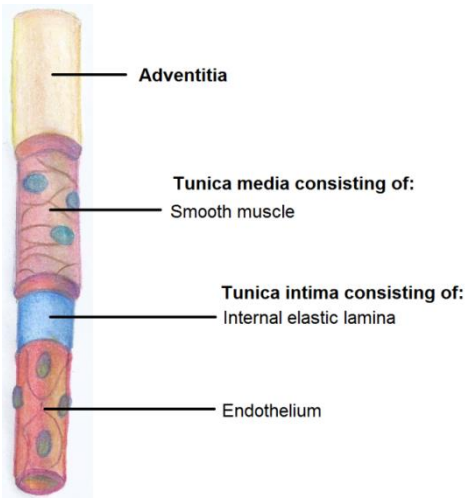

Figure 2: Anatomy of the Arteriole (Fox, 2011)

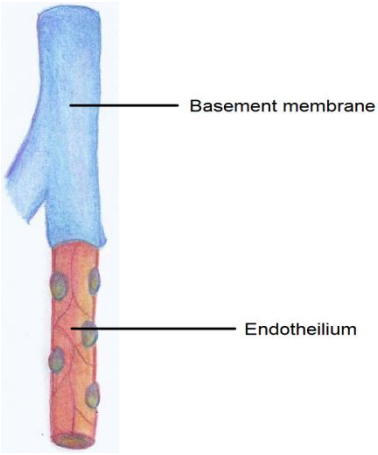

Figure 3: Anatomy of a Capillary (Fox, 2011)

2.3 THE ANATOMY OF THE RADIAL ARTERY

2.3.1 Origin of the Radial Artery

The ascending aorta is the main blood vessel that exits the heart and it distributes oxygenated blood to the arteries. The ascending aorta begins at the aortic orifice of the left ventricle of the heart and ascends approximately five centimetres to the sternal angle (bony landmark on the sternum). At the sternal angle, it then becomes known as the arch of the aorta and continues posterior to the attachment of the second right rib

onto the sternum (sternocostal joint) which is anatomically positioned to the left side of the trachea and oesophagus (Moore and Agur, 2002; Standring, 2005).

The arch of the aorta continues in a superolateral direction and gives rise to the right common carotid and right subclavian artery (Standring, 2005). The aorta then arches posteriorly, giving rise to the left subclavian artery (Moore and Agur, 2002; Standring, 2005). At this point, both the left and right subclavian arteries have branched off. The right and left subclavian arteries continue their course and give rise to the right and left axillary arteries respectively at the lateral edge of the first rib. The axillary artery then passes posterior to the pectoralis minor muscle, giving rise to the brachial artery posterior to the fold of the axilla (Moore and Agur, 2002; Stedman, 2006). The brachial artery courses down the arm until it reaches the bicipital aponeurosis and terminates into the ulnar and radial arteries (Moore and Dalley, 2005).

2.3.2 Course of the Radial Artery

The course of the radial artery consists of three parts, the forearm, the wrist and the hand (Williams and Warwick, 1980; Moore and Dalley, 2005). The radial artery begins its course in the cubital fossa (a triangular area viewed from the anterior side of the elbow) as a continuation of the terminal branch of the brachial artery. The first part beginning in the cubital fossa which lies medial to the neck of the radius (Moore and Agur, 2002; Standring, 2005) one centimeter below the elbow crease (Williams and Warwick, 1980). The radial artery then passes inferolaterally to the brachioradialis muscle where it is covered for a short distance by this brachioradialis muscle. It then continues on the anterior plane of the radial bone (Moore and Agur, 2002; Standring, 2005) with only a covering of skin and deep and superficial fascia (Williams and Warwick, 1980). The upper third of the artery lies lateral to pronator teres muscle and medial to the brachioradialis muscle while the lower third of the artery lies medial to the brachioradialis muscle and lateral to the flexor carpi radialis muscle. Thus, demonstrating how the radial crosses over during its course in the forearm (Williams and Warwick, 1980).

The second part starts with the artery passing onto the dorsal surface of the carpus (wrist bones) between the radial collateral ligament of the wrist and abductor pollicus longus and extensor pollicus brevis tendons (Williams and Warwick, 1980; Moore and Agur, 2002; Standring, 2005). The artery then curves around the scaphoid and trapezium (located on the lateral side of the wrist) on the floor of the anatomical snuff (a triangular deepening superior to the thumb and viewed with the thumb extended) box before entering the palm passing deep to the oblique head of the adductor pollicus. Then continuing medially (away from the thumb) across the palmer surface of the hand in between two muscles, the adductor pollicus obliquus and adductor pollicis transverses. The deep palmer arch, mainly formed by the radial artery and the anastomoses of the radial and ulnar artery at the base of the fifth metacarpal bone (small finger) (Williams and Warwick, 1980; Moore and Agur, 2002; Standring, 2005).

Although this is pathway is well documented anomalies have been observed where the radial artery begins in the midsection of the arm (Moore and Dalley, 2005) or it has a tortuous course down the arm (Yokoyama *et al*., 2000).

2.3.3 Radial Artery Diameter

Shima *et al.* (1996) removed the radial artery from 52 Japanese cadavers and found a mean diameter of 2.3 ± 0.5 mm. The measurement was taken one cm distal to the bifurcation of the brachial artery into the radial and ulnar artery using a stereoscopic microscope and digital measuring system. Yoo *et al.* (2005) found that out of 1 191 cases studied with the use of a two-dimensional (2-D) ultrasonography, the radial artery diameter in males equalled 2.69 ± 0.4 and 2.43 ± 0.38 mm in females using two-dimensional (2-D) ultrasonography. Loh *et al.* (2007) found in a mixed population (n=327) of 225 males and 102 females, a radial artery diameter mean of 2.4 ± 0.5 mm was reported with the use of duplex Doppler ultrasonography. Ku *et al. (*2006) performed a study on the thickness of the radial artery in pre-dialysis uremic patients, fifteen healthy subjects were used as the control and a mean diameter of 2.34 ± 0.37 mm was found in the control group with the use of Doppler ultrasonographer. Yoon *et al.* (1998) revealed out of 619 cases in a Korean population, a mean radial artery

diameter of 2.7 ± 0.4 mm, with the use of 2-D ultrasonography. This study reported a higher mean compared to the previous studies. Comparison with a South African population was not possible due to a lack of available literature.

2.3.3.1 Factors effecting radial artery diameter

Loh *et al.* (2007) assessed factors influencing the radial artery diameter and found (n= 327) that the male sex, a high lipid value (cholesterol) and hypertensive patients showed an increased radial artery diameter. However, participants suffering from diabetes mellitus and those with increasing age showed a decrease in radial artery diameter. Race, smoking and renal failure had no significant influence on radial artery diameter (Loh *et al*., 2007). Huzjan *et al.* (2004) concurred with Loh *et al*. (2007) that males have a larger diameter compared to females (n=127) and in a report by Khder *et al.* (1997), the patients that had hypertension showed an increased arterial diameter compared to a healthy control group that were matched by gender and age. Ku *et al.* (2006) study involved (n=75) and found that the hypertensive patients (n=17) had a lower baseline diameter of 2.08 ± 0.31mm compared to the healthy group (n=15) of 2.34 ± 0.37mm (p = 0.039) and the uraemic (n=43) patients had the smallest radial artery diameter of 1.85 ± 0.48mm (p = 0.001). The difference in the baseline measurements of the hypertension patients in the study done by Khder *et al.* (1997) and Ku *et al.* (2006) could be attributed to the difference in the methodology used. Khder *et al.* (1997) used echo tracking and digital photoplethysmography while Ku *et al.* (2006) used a high-resolution ultrasonography unit to capture the results.

2.4 BLOOD PRESSURE

When assessing blood flow, blood pressure and its regulating factors need to be considered. Blood pressure is explained as the force of the blood pushing directly onto the internal vessel wall and is expressed in millimeters of mercury (mmHg) (Guyton and Hall, 2006; Widmaier, 2008). The mean arterial pressure in the cardiovascular system is important, due to its large role in ensuring adequate blood flow to organs (Widmaier, 2008). A healthy arterial blood pressure reading in a large artery is normally a peak

value of 120 mmHg, known as the systolic pressure with a drop to 80 mmHg, known as the diastolic pressure in an adult in each cardiac cycle. The standard for describing a blood pressure measurement is the systolic blood pressure value over the diastolic blood pressure value e.g. 120/80 mmHg. The difference between the systolic and diastolic reading is 40 mmHg and is referred to as the pulse pressure (Ackermann, 2004; Guyton and Hall, 2006; Widmaier, 2008). The pulse pressure value can change according to the stiffness of the aortic vessel and the stroke volume (SV) (Ackermann, 2004; Guyton and Hall, 2006). Ganong (2001) defines SV as the amount of blood each ventricle is pumping out per heart beat.

2.4.1 Factors Controlling Blood Pressure

The mean systemic arterial blood pressure is influenced by either central or peripheral factors (Davies *et al*., 2001; Hirofumi, 2006; Widmaier, 2008).

2.4.1.1 Central factors

Blood pressure is influenced by SV and cardiac output (CO) (Ganong, 2001). CO is the volume of blood that is ejected each minute from the heart into the aorta, which is between four to six litres a minute at rest (Guyton and Hall, 2006). CO is derived by multiplying the SV in millilitres by the heart rate (HR) in beats per a minute (Pocock and Richards, 2006) and is influenced by preload, after load and contractility of the heart. Preload is the degree of myocardial distension on the muscle prior to contraction (Vincent, 2008). After load refers to the load of the blood against the ventricular wall which the heart muscle must exert a contractile force against to eject the blood (Guyton and Hall, 2006; Vincent, 2008) and contractility is a semi-quantitative measure of ventricular function (Gupta, 2012); increased contractility of the heart will result in a greater CO (Vincent, 2008). Blood pressure will increase when CO increases (Pocock and Richards, 2006).

2.4.1.2 Total peripheral vascular resistance (TPVR) and blood volume

TPVR is the resistance of all the systemic blood vessels (Widmaier, 2008). It is influenced by three main factors. Firstly, blood vessel diameter; a small reduction in the

vessels diameter can result in a vast in the velocity blood flow and increase in blood pressure (Sherwood, 2001; Porth, 2011). The second factor is fluid viscosity, blood is a non-homogenous liquid, containing blood cells, platelets, fat globules and plasma proteins that all contribute to the velocity of blood flow (Porth, 2011). Blood becoming viscous increases the resistance to blood flow which is caused by an increase in the fluid thickness and number of particles increasing the friction between particles (Klabunde, 2005; Porth, 2011). The increase in viscosity will then require more pressure to pump and maintain the same volume of viscous fluid (Klabunde, 2005). The third factor is the vessel length which is considered a constant as it does not normally change (Klabunde, 2005; Porth, 2011).

2.4.2 Mechanisms Controlling Blood Pressure

It is important to maintain a relatively constant blood pressure as blood flows to various parts of the body, therefore, blood pressure has both short-term and long-term regulating mechanisms (Kindlen *et al.,* 2003; Pocock and Richards, 2006; Porth, 2011).

2.4.2.1 Short-term regulatory mechanisms

The short-term regulators act over minutes or hours and are for temporary corrections in blood pressure e.g. physical exercise, postural changes and acute haemorrhagic incidents (Porth, 2011). Short-term regulation uses mainly neural and hormonal mechanisms (Porth, 2011). Small arteries and arterioles can be stimulated by the sympathetic nervous system, causing them to constrict which will in turn increase the peripheral vascular resistance (Porth, 2011). The main short-term regulator is the baroreceptor mechanism which is an intrinsic circulatory reflex located in the carotid sinuses in the walls of the internal carotid artery (right and left) and in the aortic arch (Ackermann, 2004; Guyton and Hall, 2006; Porth, 2011), known as the aortic arch baroreceptor (Widmaier, 2008). Baroreceptors are highly sensitive to stretch or distortion and work in a negative feedback loop (Kindlen *et al.,* 2003). If there is a drop in arterial blood pressure, there will be decreased pressure exerted on the wall of the artery which will activate the baroreceptors resulting in a sympathetically induced vasoconstriction and an increase in heart rate causing a rise in peripheral vascular

resistance and a resultant increase in blood pressure. Similarly, there is an opposite reaction to an increase in blood pressure (Kindlen *et al.,* 2003; Porth, 2011).

Another intrinsic circulatory reflex is the chemoreceptors which are located in the carotid bodies where the two common carotids arteries bifurcate and in the aortic bodies located in the aortic artery. These receptors have the ability to communicate with the cardiovascular centres and are able to cause widespread vasoconstriction when arterial pressure drops and carbon dioxide and hydrogen ions build up causing an increased demand for oxygen (Porth, 2011). Antidiuretic hormone (ADH) also known as vasopressin and released by the posterior pituitary gland is a powerful vasoconstrictor and increases water retention by the kidneys causing an increase in blood volume and overall blood pressure (Davies *et al.,* 2001; Pocock and Richards, 2006; Porth, 2011). The increased blood pressure and volume is counteracted by the secretion of arterial natriuretic peptide (ANP) from the atrial myocytes of the heart (Pocock and Richards, 2006).

The renin-angiotensin-aldosterone system works for both short and long-term regulation; during short-term regulation, it has a strong vasoconstriction action of arterioles and mildly of veins thus, increasing the peripheral vascular resistance (Porth, 2011).

2.4.2.2 Long-term regulatory mechanisms

Long-term regulative mechanisms are responsible for daily, weekly and monthly control of blood pressure (Porth, 2011). The adrenal medulla is responsible for secreting adrenalin which acts upon the heart muscle to bring about an increased force and rate of cardiac muscle contraction and vasoconstriction of the peripheral blood vessels thereby effecting blood pressure (Noble *et al.*, 2007). The renin-angiotensin-aldosterone system involves the juxtaglomerular cells of the kidney that synthesize and store an enzyme called renin. Renin is released into the blood stream when there is an increase in sympathetic nervous system activity or a decrease in any of the following factors: blood pressure, extracellular sodium concentration and extracellular fluid volume

(Guyton and Hall, 2006; Porth, 2011). The long-term regulation of renin-angiotensin system can be credited to the release of aldosterone from the adrenal gland which activates the kidneys to increase the sodium and water retention, thereby, increasing fluid volume and aiding in restoring blood pressure equilibrium (Davies et al., 2001; Porth, 2011).

2.4.3 Factors that can affect Blood Pressure

There are many factors that can influence blood pressure such as:

- The intake of nicotine through for example: smoking cigarettes which increases the heart rate and blood pressure immediately (Kool *et al*., 1993; Omvik, 1996).
- Regular over-consumption of alcohol can lead to an increase in blood pressure (Djousse and Mukamal, 2009) with the possibility that having four or more alcoholic drinks in one sitting may cause an increase in blood pressure temporarily (Sheps, 2012).
- Caffeine for example: coffee, tea, caffeine containing energy drinks raises blood pressure temporarily (Noble *et al.*, 2007; Sheps, 2011).
- Physical activity causing an increase in blood pressure (Vongpatanasin, 2011). Individuals that are hypertensive will have a greater rise in blood pressure (Vongpatanasin, 2011), while physical inactivity increases your chances of developing hypertension (Stress and Blood Pressure, 2013).
- Stress which is known to temporarily raise blood pressure but has not yet been demonstrated to cause a long lasting increase in blood pressure (Stress and Blood Pressure, 2013).
- The intake of excessive amount of sodium or low intake of potassium (Appel *et al*., 2006); and being an overweight or an obese individual (Appel *et al.*, 2006; Stress and Blood Pressure, 2013).
- Increasing age which has been shown to increase the thickness and stiffness of the aorta which in turn increases systemic blood pressure (Schwartz and Zipes, 2011). The aging process also increases the stiffness of the peripheral vessels

that contribute to an increase in blood pressure (Lakatta and Levy, 2003; Schwartz and Zipes, 2011).

- Secondary hypertension that can develop from certain drugs e.g. non-steroidal anti-inflammatory drugs, corticosteroids, anabolic steroids, carbenoxolone and sympathomimetic drugs (Boon, 2006), as well as from kidney disease, adrenal gland tumours and congenital structural abnormalities of the aorta (Stress and Blood Pressure, 2013).

2.5 BLOOD FLOW AND ITS REGULATING FACTORS

Guyton and Hall (2006) refer to blood flow as the amount of blood to flow past a specific point during a specific duration of time. The measurement is usually recorded in litres per minute (l/min) or millilitres per minute (ml/min) and can be substituted with millilitres per second or any other unit of flow e.g. centimetres per second ($cm.s^{-1}$) (Guyton and Hall, 2006).

Blood normally flows in a characteristic streamline pattern at a steady rate through long smooth vessels and this is referred to as laminar or streamline flow (Ganong, 2001; Guyton and Hall, 2006).

A physical law, Poiseuilles law is an equation that shows the factors that govern the velocity of blood flow:

$$Q = (L \times V) / r4$$

Where: Q (laminar flow) equates from the product of: L (length of the vessel) and V (blood viscosity) divided by r (radius of the vessel) to the power of four (Davidovits, 2007).

Blood flow though a vessels lumen is under the influence of two elements; firstly the pressure difference which is the force that is used to drive the blood through the vessel. This pressure difference is controlled by the gradient of pressure from one end of the

vessel to the other end. Secondly, the impediment of blood flow known as the vascular resistance. The blood flow (q) through a vessel is calculated by Ohm's law (Guyton and Hall, 2006):

$$q = \Delta P / R$$

$$\Delta P = P1 - P2$$

Where: R represents the resistance of the blood vessel; ΔP is the pressure difference and is equal to the pressure at the beginning of the vessel, P1 minus the pressure at the other end, P2 (Guyton and Hall, 2006).

One of the major factors controlling blood pressure is blood flow (Guyton and Hall, 2006). Higher blood pressure results in a greater velocity of blood flow whereas low blood pressure causes a lower velocity of blood flow. Local blood flow is in turn governed by two mechanisms. Firstly, an acute control mechanism (mainly the baroreceptor mechanism, (Section 2.8.2.1), which can produce a swift change in vasoconstriction and vasodilation of precapillary sphincters, metarterioles and arteries within seconds to minutes. Long-term control (mainly hormonal, refer to section 2.8.2.2) which increases or decreases the physical size and numbers of blood vessels occurring over a period of days, weeks or months (Guyton and Hall, 2006).

2.5.1 Mechanisms of Vasodilation and Vasoconstriction

Vasodilation and vasoconstriction are under the control of both nerve and chemical stimulation (Waugh and Grant, 2010). The smooth muscle in the tunica media of blood vessels have a baseline level of nervous activity, mainly sympathetic nerve stimulation as most vessels do not have a parasympathetic nerve supply. Therefore, lumen diameter and tone is controlled by the degree of sympathetic nerve stimulation (Waugh and Grant, 2010). In addition to neural stimulation, there is also hormonal stimulation in the form of vasodilator agents that cause an increase in lumen diameter (vasodilation) and vasoconstrictor agents that cause a decrease in lumen diameter (vasoconstriction) (Ganong, 2001; Klabunde, 2005).

2.5.1.1 Vasodilation

Vasodilation will occur when the metabolic need increases by the tissue, or if there is a decrease in the availability of oxygen or some other nutrient/s that the tissue requires (Waugh and Grant, 2010). A decrease in sympathetic nerve stimulation causes the smooth muscle to relax, thinning the vessel wall, thereby, causing the lumen diameter to increase and the vascular resistance to decrease (Waugh and Grant, 2010). The main vasodilator substances include, kinins (predominantly bradykinin), certain prostaglandins, histamine (Guyton and Hall, 2006; Waugh and Grant, 2010). Kinins act as powerful vasodilators and increase capillary permeability (Solomon et al., 1990). An allergic reaction or inflammation that is a result of tissue damage causes histamine release, a powerful arteriole dilator. Histamine also increases capillary porosity (Guyton and Hall, 2006).

Other factors that cause vasodilation include raised body temperature e.g. environmental influence, hyper-metabolic states and physical exercise which results in the blood vessels in the skin dilating because the sympathetic stimulation of the posterior hypothalamus is decreased (Guyton and Hall, 2006).

2.5.1.2 Vasoconstriction

The tunica media of a blood vessel consists of smooth muscle cells which respond to nerve and chemical stimulation which decreases the lumen diameter (Guyton and Hall, 2006; Waugh and Grant, 2010). An increase in sympathetic nervous activity causes the smooth muscle to contract and the tone to increase, which narrows the lumen diameter (Guyton and Hall, 2006; Waugh and Grant, 2010). The vasoconstrictor agents consist of: angiotensin peptide, norepinephrine, epinephrine, vasopressin, prostaglandins, endothelin and serotonin (Solomon et al., 1990; Guyton and Hall, 2006). Norepinephrine is a powerful vasoconstrictor compared to epinephrine which is a mild vasoconstrictor (Guyton and Hall, 2006). These hormones are secreted in such a way that they act as a dual system of control, that is; when the body is stressed or during exercise the sympathetic nervous system is stimulated, releasing norepinephrine exciting the heart,

vein and arterioles (Guyton and Hall, 2006). The most powerful vasoconstrictor is known as angiotensin, which constricts vessels in areas of diminished blood flow and arterioles all over the body to increase TPVR (Guyton and Hall, 2006).

Vasopressin, also known as anti-diuretic hormone (ADH), is a powerful vasoconstrictor secreted by the posterior pituitary gland (Guyton and Hall, 2006). Endothelin causes vasoconstriction and is found within all or most blood vessels and is released in reaction to blood vessel damage, ranging from a crushing tissue insult to traumatising chemical injectables (Guyton and Hall, 2006). The sympathetic centres in the posterior hypothalamus can be stimulated when the body temperature is low and this stimulation causes cutaneous vasoconstriction to correct and raise the temperature of the body (Guyton and Hall, 2006).

2.5.2 Conditions that can affect Blood Flow

Raynaud's disease causes narrowing of blood vessels, usually in the fingers and toes, thus reducing blood flow in these digits (A.D.A.M. Medical Encyclopaedia, 2013). Diabetes can damage blood vessels, which impairs the regulation of blood flow (Diabetes, Heart Disease, and Stroke, 2013). Local trauma or infection leads to an inflammatory process, causing increased blood flow to that area (Drake, 2007).

2.6 METHODS TO MEASURE BLOOD FLOW

Various methods exist to record/measure blood flow within a vessel. These can be separated into two categories: invasive and non-invasive methods.

Selected invasive methods are discussed below:

Indicator Dilution – Indicators: isotonic saline (Panday and Kumar, 2007), electrolytes, dyes and radioisotopes (Meier and Zierler, 1954) are injected into the blood to assess blood flow (Meier and Zierler, 1954). Although being relatively safe, there are

disadvantages as skill is needed to use the equipment to ensure accurate placement of needles and reporting of the results. It is also a very time consuming (Wood, 1962).

Electromagnetic Flowmeter - This device uses the principles of magnetic induction and does not require the blood vessel to be opened (Cromwell *et al.,* 1980; Guyton and Hall, 2006). It is extremely accurate in reading pulsatile and steady flow changes, with the ability to record these flow changes in under 0.01 seconds (Guyton and Hall, 2006). Problems around the use of this device arise due to the fluid that is located externally from the lumen of a vessel being more conductive than the wall itself. Thus shunting the flow signal and errors occur due to the varying ratios of conductivity between the wall of the blood vessel and blood itself (Webster, 1978).

There are several non – invasive methods for measuring blood flow these include but are not limited to:

Plethysmography - This apparatus measures volume changes in different areas of the body by a pulse volume recorder. The method of measuring the volume change requires the placement of a cuff. Air is then pumped into the cuff which may be placed at a given point on the upper or lower limb. The volume change in the cuff is then recorded by a transducer (Gerhard-Herman *et al*., 2006). Robinson and Buono (1995) stated that plethysmography is not able to record the volume change in isolated tissue but it can reliably measure total limb volume changes. Practitioners usually use this method to measure blood flow so to determine if blockage of a vessel or a blood clot is present (Gerhard-Herman *et al*., 2006).

Laser-Doppler Flowmetry - This device estimates the perfusion of blood in the microcirculation (arterioles and capillaries). A single-frequency laser light is used to scan the tissue and red blood cells within the tissue (Fredriksson *et al*., 2012) and the backscatter of light is used to estimate blood perfusion. It is unable to give an absolute measure limiting its use in the clinical setting, however, it is used in the research environment especially when assessing the skins circulation (Fredriksson *et al*., 2012).

Doppler Ultrasound - The most commonly used today is the Doppler Ultrasound. It is a harmless, low-cost, non-invasive accurate technique to measure the blood flow in the peripheral vessels (Salonen *et al*., 1993; Aminbakhsh, *et al*., 1999; Benedetto *et al*., 2001). This unit can accurately evaluate functional circulation and morphological changes (Rodriguez *et al.*, 2001). The moving objects in the body reflect sound waves, the unit then measures the frequency changes of the sound waves, known as the Doppler effect (Bentley, 2004) or Doppler frequency shifts (Rubin, 1994). Doppler ultrasound is a non-invasive alternative procedure to arteriography and venography when used to monitor arterial reconstruction and bypass grafts and for the evaluation of an artery post-injury (Sheps, 2007). Doppler imaging is used and valued by the following practitioners: obstetricians and gynaecologists, surgeons, general practitioners, cardiologists and dermatologists to assess soft tissue and blood flow (Liang *et al*., 2011). There are no risks or adverse reactions with the use of this technique (Levin, 2013).

Images may be either two-dimensional, in which there is a succession of image slices taken, allowing a single image to be viewed by the user at a time or three-dimensional (3D), in which volume of echoes (over a thousand image slices in succession) are stored in a digital format and create a 3D image (Evans and McDicken, 2000). Four modes are used with a Doppler (Cromwell *et al.*, 1980), they include the two most common modes of Doppler used for blood flow measurements: continuous-wave Doppler and range-gated pulse Doppler (Rubin, 1994). The two less common modes are pulse ultrasound, pulsed Doppler (Cromwell *et al.*, 1980). Doppler ultrasound has four types viz., Duplex Doppler (bedside), colour Doppler, power Doppler, continuous-wave Doppler (Grainger *et al.*, 2001).

The oldest and simplest Doppler sampling technique is continuous-wave Doppler also known as bedside (Rubin, 1994). It uses two transducers, one to transmit and the other to receive (Rubin, 1994). It detects the pitch changes of sound waves providing measurements of the blood flowing through an area or blood vessel lumen (Grainger *et al.*, 2001) and does not produce a depth resolved image (Rubin, 1994). Duplex Doppler combines conventional ultrasound with Doppler ultrasound to provide information on the

blood flowing through arteries and veins (Grainger *et al.*, 2001). Colour Doppler takes the image of the blood vessel and overlays colours by a computer to produce a colour image (Evans and McDicken, 2000).

The Doppler ultrasound is frequently used to measure and visualise the radial artery diameter (Yoon *et al*., 1998; Yoo *et al*., 2005; Ku *et al*., 2006; Topp *et al*., 2013) and radial artery blood flow (Weston *et al*., 1994; Topp *et al*., 2013). Ku *et al*. (2006) found ultrasonography to be significantly accurate ($p < 0.001$) when measuring the radial artery when compared to histological measurements.

2.7 CRYOTHERAPY

Cryotherapy is used for therapeutic purposes both locally (Michlovitz, 1996) and systemically (Nemet *et al*., 2009) as it produces the following physiological effects (Hubbard *et al*., 2004; Michlovitz, 1996):

- Vasoconstriction
- Reduction in blood flow
- Increased blood viscosity
- Reduced metabolic rate
- Localised neural inhibition

Cryotherapy has a wide range of therapeutic uses, such as for acute injuries, including: soft tissue contusions, ligament sprains and muscle strains, and for post-surgical uses, in the reduction of pain, inflammation, muscle spasm, decrease bleeding and oedema and to reduce chronic joint effusion (Michlovitz, 1996). Increasing the pain threshold in an acute musculoskeletal injury is a crucial and necessary reason to apply cryotherapy (Michlovitz, 1996; Hubbard *et al.*, 2004). The cold sensation of tissue cooling occurs as heat from the deeper tissues is transferred through the tissue layers towards the cryotherapy modality, known as conduction of heat and not the cold pack transferring cold to the tissue. This mechanism of conduction of heat can be accredited to the

reduction in oedema, muscle spasm and pain (Enwemka *et al*., 2002; Merrick *et al*., 2003).

Hocutt (1981) described four phases of sensation to the application of cold, with the first being a cold feeling, lasting from one to three minutes. The cold sensation is due to the heat being transferred from the tissue towards the cryotherapy modality, therefore, cooling the tissue indirectly (Hubbard *et al*., 2004). During the second stage, an aching or burning sensation is experienced from two to seven minutes after cryotherapy is initiated. The third stage is a local numbness or an anaesthetic sensation occurring within five to 12 minutes of application due to local nerve fibre conduction velocity decreasing. During the fourth stage, the pain and reflex impulses are inhibited at 12 to 15 minutes (Hocutt, 1981).

2.7.1 Mechanism of Action

Vasoconstriction and reduced blood flow:

Cryotherapy modalities applied to an area will constrict cutaneous blood vessels (Cameron, 1999), decreasing the flow of blood which will continue for some time after the cryotherapy application has been removed (Topp, *et al*., 2009; Fiscus *et al*., 2005). According to Cameron (1999), there are two mechanisms that cause cold induced vasoconstriction. The direct mechanism, whereby the thermal sensors in the skin are stimulated (Folkow *et al*., 1963) resulting in vasoconstriction of the local blood vessel from an increase in sympathetic output, norepinephrine and Rho kinase activity (Faber, 1988; Bailey *et al*., 2004). Stimulation of the thermal sensors occurs as a result of cold-induced, selective augmentation of αlpha2-adrenoceptor (α2-AR) reactivity on the smooth muscle cells in the cutaneous blood vessels. This will result in a cutaneous blood vessel vasoconstriction with a resultant reduction in blood flow (Bailey *et al*., 2004).

The indirect mechanism reduces vasodilation by decreasing the production of vasodilator mediators. The resultant vasoconstriction leads to a reduction in localised flow of blood to that area with consequential reduction in the inflammatory rate and

decreased intravascular fluid pressure. This causes a decrease uptake of fluid into the surrounding cellular interstitium, thus, decreasing the amount of swelling in the area (Cameron, 1999).

Vasoconstriction of the blood vessels decreases the rate of blood flow, local metabolism, vasoactive agents e.g. histamine and reduced nerve excitability (Schafer and Faye, 1990). This makes vasoconstriction very effective in controlling pain, inflammation and oedema (Michlovitz, 1996; Cameron, 1999). This is because it decreases the amount of initial oedema after an injury so it is a crucial step in reducing the amount of pain. The decrease in blood flow, local metabolism and vasoactive agents also speeds up the process in restoring the normal range of motion (Reid, 1992). Bleakley *et al*. (2004) highlighted through a systemic review that vasoconstriction of blood vessels decreased pain and swelling immediately post-injury up to one week.

An accumulation of studies have evaluated the implications that cryotherapy has on blood flow to provide a rationale for the use of cryotherapy to limit swelling and cellular injury in acute musculoskeletal injuries. Topp *et al*. (2013) documented a reduction in blood flow ($p< 0.05$) from baseline with the application of ice at five, ten, fifteen and 20 minutes with no change in arterial diameter. Weston *et al*. (1994) achieved a reduction in blood flow after applying a cold gel pack for 20 minutes while Karunakara *et al*. (1999) found that intermittent application with an ice pack for 60 minutes resulted in a significantly lower blood flow compared to a single application for 20 minutes. According to Chu and Lutt (1969), the application of cryotherapy should remain on for no less than 20 minutes to allow for a three to five minute period of vasodilation before going into a second period of vasoconstriction.

Ho *et al*. (1994) did a trial to determine the effect of an ice wrap on bone metabolism and changes in blood flow (n=21). Each knee of the participant was wrapped with either an ice or room temperature (control group) wrap for 20 minutes. A triple phase technetium bone scan measured the blood flow, with results of a mean decrease in arterial blood flow (38.4%, ± 4.97) and soft tissue blood flow (25.8%, ± 2.04) and in

bone uptake (19.3%, ± 2.0). Abramson *et al*. (1966) found blood flow to decrease after submerging both hands into an 11 to 14°C cold water bath for 25 minutes.

Blood viscosity:

The cooling effect following cryotherapy increases the viscosity of blood, increasing the resistance to blood flow (Swenson *et al*., 1996).

Metabolic rate:

The reduction in the metabolic rate from the application of cryotherapy allows tissues to survive for longer periods of time (Hubbard *et al.*, 2004; Schafer and Faye, 1990; Seiyama *et al*., 1990). The cooling mechanism reduces nerve conduction velocity leading to a decrease in Adenosine Triphosphate (ATP) requirements and the ongoing chemical reactions. Thus allowing the oxygen demand in the damaged hypoxic tissue to decrease which increases the duration of survival of the tissue (Hubbard *et al*., 2004). Sapega *et al*. (1988) found that muscular ATP requirements decreased in an amputated cat limb at temperatures between 5°C and 22°C and the ATP requirements increased at 1°C.

Decreased nerve conduction:

Saeki(2002) reported that the relief of pain could be attributed to a decreased nerve transmission velocity, reduction of nociceptor transmission, reduced muscle contraction and metabolism. Thus decreasing the temperature of peripheral nerves can decrease the conduction velocities along the motor and sensory nerve bodies (Michlovitz, 1996; Mac Auley, 2001). Algafly and George(2007) found that using cryotherapy on an ankle injury/sprain increased pain threshold and pain tolerance and that it is plausible that the pain reduction was due to the reduction of the nerve conduction velocity. Herrera *et al.* (2010) found that cryotherapy (n=36) reduced nerve excitability, decreased pain perception either due to a decrease in pressure on the nerves or through diminished afferent loop stimulation leading to a decrease in muscle spasm (Michlovitz, 1996; Hocutt, 1981).

Melzack and Wall (1965) described how using the gate control theory influenced the perception of pain. Small myelinated A-delta fibres and unmyelinated C-fibres relay peripheral pain to spinal column (dorsal horn). The gate control theory involves the A-delta and C-fibres interacting with the large A-alpha and A-beta fibres, where the larger myelinated nerve can abolish or interfere with the pain signals by simultaneous inputs, therefore, decreasing an individual's perception of pain (Melzack and Wall, 1965). According to Hubbard *et al*. (2004), this inhibition of pain can last post-cryotherapy application for 30 minutes.

Hayward *et al*. (2006) performed a clinical trial that involved 20 participants in the intervention group and 20 participants in the control group. Both groups received two lignocaine injections into the hallux; the intervention group received six minutes of ice application prior to the injection. The intervention group had reduced pain using a visual analogue pain scale during the injection compared to the control group receiving no ice; indicating that the application of ice had an effect on the perceived level of pain.

2.7.2 Safety of Cryotherapy

Cryotherapy is considered to be a safe therapeutic intervention if the guidelines are followed (Freeman, 2013). The Hunting reaction or cold induced vasodilation is a protective mechanism to cold (Cameron, 1999). Tissue dropping below 10°C (usually after an application of ice for periods longer than 15 minutes), leads to reflex increase in blood flow to that area to warm the area up and prevent frostbite (Cameron, 1999). The main cause of injury from the use of cryotherapy techniques is the lack of precautions or inadequate knowledge of proper use (Meeusen and Lievens, 1986). The guidelines are highlighted below in terms of when to avoid using cryotherapy and outlined for each cryotherapy technique.

The use of cryotherapy should be avoided in the following situations (Michlovitz, 1996 and Nadler *et al*., 2004):

- Intolerance to cold
- Hypersensitivity to cold
- Cryoglobulinemia a large amount of cryoglobulin protein in the blood plasma Stedman, 2006).
- Cold urticaria (allergy to cold temperatures)
- Raynauds phenomenon
- Peripheral vascular disease or regenerating peripheral nerves (Cameron, 1999)

2.7.3 Types of Cryotherapy

There are many different methods of applying cryotherapy with each of them offering different degrees of cooling (Michlovitz, 1996; Cameron, 1999). These methods also have specific ways in which they bring about the effects of cryotherapy. The practitioner must determine how much body surface area needs to be cooled (Michlovitz, 1996) and then select the appropriate method of cryotherapy.

Cryotherapy techniques/methods include (Michlovitz, 1996; Cameron, 1999):

- Ice pack
- Cold Pack
- Ice bags
- Iced towels
- Ice cubes
- Cold baths
- Vapocoolant spray
- Controlled cold-compression units (Michlovitz, 1996; Cameron, 1999)
- Using ice to message (Michlovitz, 1996; Swenson *et al*., 1996)
- Cooling gels containing methanol (Airaksinen *et al*., 2003; Bishop *et al*., 2011) and/or anti-inflammatory properties

The various methods of cryotherapy will be discussed in order to contextualise the use of the cooling cuff and moist ice pack.

2.8 ICE AND COLD PACK CRYOTHERAPY

2.8.1 Introduction

According to Curl *et al*. (1997), ice is the most common treatment for soft tissue contusions. Ice packs are not limited to a specific form of ice. There are a number of forms including wetted ice (moist ice), cubed ice and crushed ice (Dykstra, 2009). There are various techniques to utilise this form of cryotherapy, including ice baths and ice massage (Michlovitz, 1996). Ice baths can range from temperatures of 13°C to 18°C and can easily be used at home by patients. Ice massage is usually utilised over small areas, and allows the patient to use the technique at home due to its simplicity. Cold packs are relatively inexpensive (Michlovitz, 1996) and cool tissues effectively and efficiently (Greenstein, 2007). Cold packs may contain either silica gel (Michlovitz, 1996; Cameron, 1999), a sand-slurry mixture (Michlovitz, 1996) or a saline and gelatine mixture (Cameron, 1999). They are utilised by professional and non-professionals for the management musculoskeletal injuries in an acute setting (Enwemka, 2002). Cold packs may be used for 15 to 20 minutes as they retain a sufficient cooling temperature for this time period (Michlovitz, 1996).

2.8.2 Mechanism of Action

The mechanism of action for ice packs has been outlined in Section 2.11.1 and 2.11.2. Local numbness and analgesia is achieved in five to 12 minutes of application due to the decrease in conductivity of the local nerve fibres (Hocutt, 1981), allowing a decrease in muscle spasm and pain (Fox and Sharp, 2007). Numbness of the treated area is an indication that the treatment should then cease shortly (Brown and Hahn, 2009).

2.8.3 Clinical Research

An ice application was applied to 23 subjects with ankle sprains to determine the effect of nerve conduction velocity (NCV), pain tolerance (PTO) and pain threshold (PTH). One group received cryotherapy application while the control group received no cryotherapy. The control group had no change in NCV, PTO and PTH, while the cryotherapy group showed a significant decrease in NCV and an increase in PTO and PTH ($p<0.05$) (Algafly and George, 2007). Similarly, Herrera *et al.* (2010) established that ice packs reduced NCV of the sensory nerves with a resultant decrease in the action potentials. Hubbard *et al*. (2004) also established that continual application of cryotherapy was more effective in reducing perceived pain compared to intermittent cryotherapy application and that ice was better than no ice in reducing pain post-injury. These studies indicate that ice it is an effective means of cryotherapy in terms of reducing NCV, PTO and PTH.

A comparison study between three different forms of ice revealed that moist ice was superior in reducing surface and intramuscular temperatures to cubed or crushed ice and cubed ice was superior to crushed ice (Dykstra *et al*., 2009). This study indicates that wetted ice is one of the most effective means in reducing tissue temperature. Janwantanakul (2009) did a study comparing three different weights of ice packs: 0.3 kg, 0.6kg and 0.8kg. The study revealed that the 0.6 kg ice pack was the most effective in cooling tissue temperature. This highlights the importance of the weight of the ice pack used in the effectiveness in reducing tissue temperature and is not due to the amount of local surface area covered.

There is an accumulation of studies that showed a decrease in blood flow after 20 minutes of application: Ho *et al*. (1994), Karunakara *et al*. (1999) and Topp *et al*. (2013) all applied ice and Weston *et al*. (1994) applied a cold gel.

2.8.4 Advantages of Ice and Cold Packs

Cold/Ice packs have been described as the treatment modality of choice for traumatic injuries (Nemet *et al.*, 2009).The method of treatment may be uncomfortable for a few minutes but will lead to a reduction in pain (Michlovitz, 1996). Cold packs are relatively inexpensive and require minimal skill to use, thereby, allowing for home use by patients (Cameron, 1999; Airaksinen *et al.*, 2003). Cold packs in a semi-solid state, which is between zero and 5°C, have the ability to conform to the contours of the body (Cameron, 1999). Cold/ice packs can also cover moderate to large surface areas of the body (Cameron, 1999; Airaksinen *et al.*, 2003). Chemical cold packs are also available which are activated by hitting them against a wall or your hand or squeezing them (Michlovitz, 1996).

2.8.5 Disadvantages of Ice and Cold Packs

The weight of the cold/ice pack may be uncomfortable for the patients on the injury site and removal of the cold/ice pack may be necessary to evaluate the area being treated (Cameron, 1999). Cold/Ice packs will require a freezer (Airaksinen *et al*., 2003). Cold packs require at least two hours of storage at approximately -5°C before use and only allow for a treatment time period of 15 to 20 minutes due to their rapid increase in temperature once applied. This low therapeutic time, therefore requires the need for more replacement packs if a greater treatment period is required (Michlovitz, 1996). Cold gels application is more user-friendly and convenient compared to cold/ice packs as the cold/ice packs can cause an untidy setting because of the water vapour and melting of the ice (Topp *et al*., 2009). Prolonged ice application can affect motor and muscle performance (Meeusen and Lievens, 1986). Kauranen and Vanharanta (1997) found a cold pack applied for 15 minutes on the forearm and hand in 20 healthy participants led to a delay in simple reaction time, speed of movement and tapping a hand on a table. Application time frames are not being followed correctly to achieve the therapeutic effect due to user's lack of education and understanding of the benefits. This causes the person applying the cryotherapy to not allow themselves to go through

the burning or aching feeling for a few minutes to achieve an adequate therapeutic effect (Hocutt, 1981).

2.8.6 Adverse effects of Cold and Ice Packs

Prolonged cold application can lead to frost bite (Brown and Hahn, 2009). Bleakley *et al*. (2004) investigated case reports and found that with cold application for 20 to 30 minutes, there were reports of skin burn and there had been cases where nerve damage had occurred. Drez *et al.* (1981) reported on five separate cases involving the application of cryotherapy for longer than 30 minutes resulting in nerve palsy.

2.9 COOLING GELS

2.9.1 Introduction

The majority of cold gels contain menthol (Zhang *et al*., 2008). Menthol is derived naturally from the plants in the Mentha family which are notorious for their mint taste and smell (Zhang *et al.*, 2008). Menthol has been utilised extensively for a number of years for its analgesic property (Patel *et al*., 2007) and reduction in pain in acute sports injuries (Yosipovitch *et al*., 1996). Menthol can be combined with herbal extracts or anti-inflammatory drugs to further enhance healing (Patel *et al*., 2007).

2.9.2 Mechanism of Action

Menthol does not lower the temperature of the skin, yet it gives a unique cooling feeling as cold (Airaksinen *et al*., 2003; Vasner *et al*., 2004). It is proposed to stimulate the transient receptor potential action channel subfamily M member 8 (TRPM8) cold receptors (Page, 2007; Patel *et al.*, 2007). TRPM8 senses mild ambient cold temperatures (McKemy, 2005; McCoy *et al*., 2011) and are found in sensory neurons located in the dorsal root and trigeminal ganglion and the endings of peripheral nerves (McKemy *et al*., 2002; Thut *et al*., 2003; Keh *et al*., 2011).

TRPM8 receptors' perception of temperature is controlled voltage-dependent calcium channels (Dragoni *et al*., 2006; Voets *et al*., 2007). Menthol interferes with the cell membrane of these cold receptors preventing free movement of calcium through the membrane (Hensel and Schafer, 1974; Galeotti *et al.*, 2002), reducing pain for a short duration of time (Liu *et al.*, 2005).

When Menthol gels are combined with herbal extract or anti-inflammatory drugs can enhance the treatment outcome as menthol acts as a penetration enhancer (Patel *et al*., 2007), thereby, increasing the effect of the herbs or anti-inflammatory drugs.

2.9.3 Clinical Research

Airaksinen *et al.* (2003) conducted a randomized double-blinded trial that compared menthol (3.5%) and ethanol gel application to a gel containing no menthol (placebo) (n=74) in the management of acute sports injury cases. After one week, the active gel group showed greater pain relief at rest and with activity compared to the placebo group. Similar results were found when a menthol (3.5%) containing gel and a placebo gel were applied to participants with osteoarthritis of the knee (n=20). The group receiving the menthol gel had reduced pain and improved functioning when compared to the placebo group (Topp *et al*., 2011). These studies indicate that menthol gel is an effective means to reduce pain.

Biofreeze® (a cooling gel that contains menthol, mix of botanical ingredients, Echinacea and Arnica) was compared to ice to determine its effect on pain tolerance, blood flow and muscle performance (Topp *et al*., 2009). Biofreeze® resulted in quicker reduction in blood flow than with ice but the effect wore off earlier (Topp *et al*., 2009). It was concluded that the gel was more beneficial in the earlier stages of an injury (Topp *et al*., 2009). In another study, Biofreeze® was compared to ice in participants with acute, non-complicated neck pain (n=51) (Bishop *et al*., 2011). Both treatments decrease pain levels, with the Biofreeze® showing twice the reduction in pain and a longer lasting effect than the ice (Bishop *et al*., 2011). Although these findings are favourable, these

results cannot be extrapolated to all cold therapy gels as each type of gel will contain different ingredients and may then not produce the same results.

2.9.4 Advantages of Menthol Cooling Gel and Combination Gel

Cooling gels with a menthol extract can be purchased over the counter as the food and drug administration (FDA) has permitted external application of menthol up to 16% in concentration (Patel *et al.*, 2007), therefore, making them readily available. Cooling gels with menthol extracts make it easy to transport by sport enthusiast and are very accessible compared to ice packs that require a refrigerator (Airaksinen *et al.*, 2003; Bishop *et al.*, 2011). Subjects with localised conditions and an inability to tolerate or endure the pain that comes with other forms of cryotherapy treatment can use cold gels with menthol (McGee, 2008). The use of combination gels for their analgesic property provides an alternative means to manage pain other than various forms of anti-inflammatory and prescription drugs (Topp *et al*., 2013). Bishop *et al.* (2011) advises chiropractors to use combination gels before and after treatment to decrease pain and it may be used in conjunction with other modalities as it can be advantageous in reducing a patient's apprehension.

2.9.5 Disadvantages of Menthol Cooling Gel and Combination Gel

The amount of the menthol sensitive sensors may vary from person to person, therefore, not allowing all individuals to feel the same amount of cooling sensation as the next person from a menthol gel application (Hatem *et al*., 2006).

Topp *et al.* (2009) found the long-term effects of combination gels decreases the rate of blood flow for a short duration compared to the application of ice, therefore, amounting to only a short-term effect after application which provides a need for continual application.

2.9.6 Side effects of Menthol Cooling Gel and Combination Gel

Hatem *et al.* (2006) and Harper (2010) reported no adverse side-effects from utilising menthol gel in their studies on human participants.

2.10 VAPOCOOLANT SPRAY

2.10.1 Introduction

Two types of vapocoolant sprays are available viz. Fluor-Methane® and ethyl chloride (Michlovitz, 1996; Simons *et al*., 2009). They are primarily used to induce local anesthesia and originally applied in patients with active myofascial trigger points (Michlovitz, 1996; Simons *et al*., 2009).

2.10.2 Vapocoolant Spray Mechanism of Action

Fluor-Methane or ethyl chloride liquid is contained in a container at room temperature. When the control valve is released the pressure will force out a stream of the liquid, as the stream comes in contact with the air, it starts to evaporate thus cooling the stream before contacting the skin; further evaporation cools the skin and to some degree causes direct depression of the cutaneous receptors (Simons *et al*., 2009). The sprays have an anaesthetic effect by decreasing pain in the area.

2.10.3 Clinical Research

Armstrong *et al*. (1990) assessed the effect of lidocaine and ethyl chloride compared to a control group (n=120) on pain during catheter insertion for a venepuncture (intravenous access). Both the lidocaine and ethyl chloride groups showed a statistically significant decrease in pain in comparison to the control group during the catheter insertion ($p < 0.001$).

2.10.4 Advantages of Vapocoolant Spray

The sprays are sterile and can be used without possible contamination (Simons *et al.*, 2009). The Vapocoolant spray containing Flouri-Methane is chemically stable and is non-flammable, non-explosive, non-toxic and a non-irritant to the skin (Simons *et al.*, 2009). Simons*et al*. (2009) state that the vapocoolant sprays anti-inflammatory effect alone can be effective in relieving the pain of sprains and burns.

2.10.5 Disadvantages of Vapocoolant Spray

Ethyl chloride has a low margin of safety, due to it being flammable and explosive; it should not be given to a patient for home use. This limits the ease and ability for safe home use by patients (Simons *et al*., 2009).

2.10.6 Adverse effects of Vapocoolant Spray

Vapocoolant sprays can lead to frostbite injuries on the skin if applied to one spot or sprayed too far away from the surface of the skin (Simons *et al.*, 2009) or if repeated treatments are applied without letting the skin re-warm (Michlovitz, 1996). The ethyl chloride vapocoolant spray can explode when 4-15% of the vapour is mixed with air (Simons *et al*., 2009).

2.11 COMMERCIALLY AVAILABLE COOLING CUFF

2.11.1 Introduction

The commercially available cooling cuff is a new product on the market that functions via cooling crystals (Sievers, 2006). The manufacturers claim that it can be safely utilised for up to 24 hours and results in a deep intensive cooling on the area of application, which reduces swelling and eases aches and pains (Sievers, 2006). It causes cooling at a moderate and constant temperature depending on the ambient

temperature and humidity (Sievers, 2006). Sievers (2006) states that it does not lead to the hunting reaction, due to it acting through natural evaporating mechanisms.

2.11.2 Mechanism of Action

The commercially available cooling cuff contains polymer granules found within the textile material (Sievers, 2006). The polymer granules are crystalline in the dry state and when immersed in water they absorb it, thereby, changing it to a gel state. The granules when in a gel state slowly release water to the surface of the skin allowing the body to cool through a natural evaporative process. The cooling effect of the commercially available cooling cuff lasts until the granules have lost all of the liquid present within them. This allows the cooling cuff to be used for prolong periods. The textile used allows for easy flow of the water from the granules to the surface of the skin (Sievers, 2006).

2.11.3 Clinical Research

There has been limited investigation into the claims made by the manufacturer of the cooling cuff. Evidence was given to the researcher by the director of the commercially available cooling cuff's company, Mr Sievers (2012, pers. Comm. January) on the clinical trial performed by Dr. Wiesend in 2008, using the commercially available cooling cuff in the form of a randomised control trial. This trial involved the application of a commercially available jaw mask to participants after wisdom teeth removal, (n=22), 12 of the patients received the commercially available jaw mask and 10 received no intervention. The study revealed that the participants who received the cooling cuff reported greater comfort and decreased swelling compared to the group with no intervention. The pressure exerted by the commercially available cooling cuff was said to counteract the increase in swelling in addition to the cooling effect.

There have been no studies investigating the effect of the commercially available cooling cuff on blood flow and whether the changes that occur, if any, are similar to those induced by an ice pack. The lack of formal investigation into the physiological effects of the cooling cuff may deter clinicians from utilizing the cooling cuff.

2.11.4 Advantages of the commercially available Cooling Cuff

The polymer granules inside the commercially available cooling cuff are non-toxic (Sievers, 2006). The commercially available cooling cuff is readily available for use and can be kept on while the sportsman is participating, thereby, saving crucial play time and preventing further complications. The therapeutic cooling can last up to 24 hours depending on the ambient temperature and humidity and through the process of evaporation can safely be left on for 36 hours. The commercially available cooling cuff does not require a freezer or electricity as opposed to other cooling methods and only requires the cuff to be immersed in water for 20 minutes, prior to the commencement of the therapy (Sievers, 2006).

2.11.5 Disadvantages of the commercially available Cooling Cuff

Any disadvantages of its use have not been established in relation to the available literature. Any disadvantages from utilising the commercially available cooling cuff in this study will be recorded.

2.11.6 Adverse effects of the commercially available Cooling Cuff

According to the company director, Sievers (2006), there have been no recorded reports of adverse effects to date; therefore, any adverse reactions in this trial experienced by the participants were recorded.

CHAPTER THREE

METHODOLOGY

3.1 STUDY DESIGN

This study was designed as a randomized pre-test post-test investigation, whereby two groups are tested before and after an intervention and against each other to determine the effect of the intervention (Shuttleworth, 2009). Ethical clearance was obtained from the Institutional Research Ethics Committee of the Durban University of Technology to conduct this study (Appendix K).

3.2 POPULATION

The study population consisted of people residing in the eThekwini municipality that met the inclusion criteria of the study.

3.3 RECRUITMENT

Advertisements (Appendix H) were placed at the Durban University of Technology (DUT) Chiropractic Day Clinic (CDC), around the Berea and City campuses of the DUT and at Spar shops in the area. The advertisements (Appendix H) were also distributed to various sporting teams in the greater Durban area, with participants also being recruited through word of mouth. Permission was attained to place the advertisements (Appendix I). Prospective participants were requested to contact the researcher telephonically for more information.

All prospective participants who contacted the researcher telephonically were asked the following questions to qualify:

1. “Would you mind answering a few questions to gauge your eligibility to the study?”
2. “How old are you?”
3. “Have you smoked before or are you currently smoking?”
4. “Do you suffer from any of the following: heart disease, diabetes, hypertension, or any other blood vessel disease?”
5. “Are you currently taking any medication?”

Participants who gave consent to answer the questions and who were between the ages of 18 and 45 years and answered no to questions three and four, were invited to an appointment at the DUT CDC. The participants who were taking any acute or chronic medication were thanked for their interest but were not included in the study.

On arriving at the DUT CDC, the participant was given a verbal explanation of the research procedure and a Letter of Information and Informed Consent Form (Appendix A) to read and sign. The participants were informed that they would receive a cryotherapy technique that would be applied to their forearm within the safety time margin. They were also advised that it may be perceived as temporarily uncomfortable but that once the cold application was removed, the tissue would return to normal temperature with no long lasting problems/effects. The participants were given an opportunity to ask any questions related to the study. Each participant then underwent an appointment consisting of a case history (Appendix B), an orthopaedic examination of the elbow (Appendix C) and a physical examination (Appendix D).

3.4INCLUSION AND EXCLUSION CRITERIA

3.4.1 Inclusion Criteria

Participants were included in the study if they:

1) Were between the ages of 18 and 45 (Weston *et al*., 1994). People under 18 years of age were excluded as they are considered a vulnerable population for research and those over 45 years of age were excluded due to natural age related changes occurring in older populations (Minaker, 2011).
2) Were asymptomatic in terms of any acute or current injuries to the upper limb and neck.
3) Had no history of trauma or surgery to the neck, elbow, hand and wrist.

3.4.2 Exclusion Criteria

Participants were excluded from the study if:

1) They had previously smoked or who were currently smokers.
2) They reported a history of cardiovascular and/or peripheral vascular disease and/or diabetes or if any of these were found during the physical examination.
3) Vascular abnormalities were found during the physical examination or through the case history (venous thrombosis, emboli, bleeding disorders).
4) They had consumed alcohol within the last 24 hours.
5) They had consumed caffeine, other stimulants, viz. Energy drinks or drugs, recreational drugs or any other drug intake in the last 24 hours which may have had an effect on their blood flow or lumen diameter.
6) They had being involved in any physical activity (any activity that increases cardiac output e.g. running, going to the gym, lifting weights, playing sport, etc.) in the preceding 24 hours.

3.5 SAMPLE ALLOCATION AND SIZE

A sample size of 50 participants was recruited for the study (Esterhuizen, 2013). A feasibility study was conducted on 10 participants after informed consent was obtained (Appendix J), the effect size was calculated (n=196) but due to limitations placed on the study in terms of available resources a smaller sample size was selected (Esterhuizen, 2013). The study was exploratory so it was estimated that with this sample size one would be able to see trends in the data (Esterhuizen, 2013).

The participants that met the inclusion criteria were then allocated into one of two groups using the probability sampling hat method (Castillo, 2009). Fifty pieces of paper were divided into two groups of 25; each piece of paper had either group one or two written on it, which was then placed in a bag. The participant then selected a piece of paper from the bag allocating them to one of the two groups.

- Group One – Moist ice pack (control group)
- Group Two – Commercially available cooling cuff (experimental group)

3.6 MEASUREMENT TOOLS

A Siemens ACUSON X300™ ultrasound system, premium edition was used in this study. The colour flow mode was used to find the blood vessel. The B-mode was then utilised to measure the radial artery diameter and the pulse wave Doppler was used to measure the velocity of the blood flow. A 13.5 Mega hertz transducer was used.

A qualified diagnostic ultrasonographer who was employed by the DUT Radiography Department (Appendix G) conducted all ultrasonography. No blinding procedure was utilised. Permission was sought from the Head of Department (HOD) of Radiography and the ultrasonographer for the utilisation of the ultrasound machine in this study (Appendix G).

3.7 INTERVENTION METHOD, FREQUENCY

3.7.1 Method

The study interventions included:

Ice pack – A 2 kg packet of ice cubes was purchased and placed in the freezer (minus 18 C°) to prevent the ice cubes from melting until the ice was required for the trial. A moist ice pack was made by removing the ice cubes from the freezer and placed into a damp kitchen cloth and measured to required weight of 0.6 kgs, the cloth was closed with an elastic band. The participant was asked to flex their elbow to 90 degrees, the researcher then placed his second and third fingers of his right hand parallel to the crease; a mark was then made with a skin marking pencil at the boarder of the third finger on the ventral surface of the participant's forearm. The moist ice pack was then placed so that the edge of the moist ice pack met the pencil mark and a towel was placed over the moist ice pack and lightly tucked underneath the patient's forearm, which was resting on the table to stabilise the participant's arm position.

Commercially available cooling cuff – The cooling cuff utilized in this study was 33 cm in length and 16 cm in width, with velcro on either side to allow it to fit comfortable around the body part. Cooling crystals are embedded in a textile fabric (Öko Tex 100, high Tech™ Micro) which are non-toxic. The cuff is manufactured by a German based company (Lindenstrasse 6, D-49586 Neuenkirchen, Germany). The participants were requested to flex their elbow to 90 degrees; the cuff was then placed on their right forearm, starting at the level of the elbow crease. The Velcro straps where then secured to maintain the cuffs position. The manufacturing company sponsored the commercially available cooling cuffs for this study (Appendix F).

Figure 4: Commercially available cooling cuff (Sievers, 2006)

3.7.2 Frequency

The participants (n=43) attended two consultations. The initial consultation was a physical examination, followed by the intervention which was conducted within five days of the first consultation.

3.8 RESEARCH PROCEDURE

Once the participant met the inclusion criteria, an appointment was made at the DUT Radiography Clinic (within 5 days of the initial consultation). The participants were instructed to avoid alcohol, caffeine, and physical exercise for 24 hours before and on the morning of the appointment.

The participant met the researcher at the Radiography Clinic for their second appointment, which lasted approximately 40 minutes. The researcher then asked the participant if he/she had ingested any alcohol, caffeine or taken part in any physical exercise in the last 24 hours; if the answer was no, then the research proceeded and the participant was then introduced to the ultrasonographer.

The participants name was then checked on the list to see which group they were allocated to and asked to remove any clothing covering the area below the elbow (when a clinic gown was required, it was then provided for the participant). The participant was then asked to relax in a chair for 20 minutes, which was timed on a stop watch, while the relevant cooling product was attained, allowing the participant to acclimatize to the room's environment. The room's air-conditioning unit was set between 22-23°C and checked prior to the participant's appointment. This enabled the environment to be controlled.

The participant was instructed to place their right forearm on the table with the palm of their hand facing up. The baseline measurements were taken for radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) using the Doppler ultrasound five minutes before the cryotherapy technique was applied. The respective cryotherapy was applied as outlined above, and during this time the participant was requested to relax in the chair keeping their forearm resting on the table. After 15 minutes the radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) measurements were re-taken while the moist ice pack/ commercially available cooling cuff was still in place. Fifteen min duration of application was selected in this study to prevent a reflex increase in blood flow to the area which occurs after applications longer than 15 mins of cryotherapy, when tissue reaches 10°C (Cameron, 1999).

After the measurements were obtained the cryotherapy intervention was removed and the participant was thanked for their time and allowed to leave.

3.9 CONSORT FLOW DIAGRAM

The consort statement was included to give an account for the participation exclusion (Figure 4). Fifty participants were assessed for their eligibility for this study. Seven participants were excluded due to their blood pressure readings being greater or equal to 140/90 mmHg. This was in the exclusion criteria as hypertension is a cardiovascular disease.

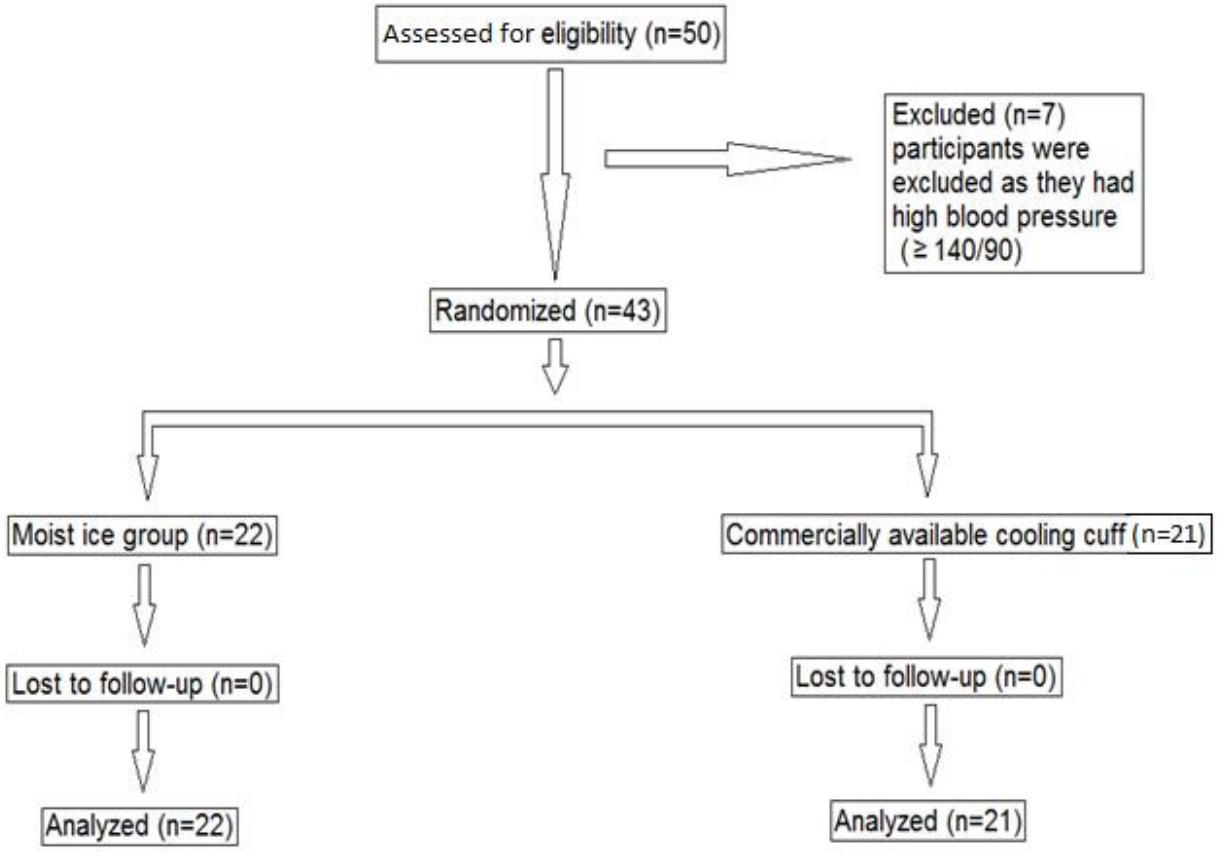

Figure 5: Consort Flow diagram of participation in the research study (Consort-statement, 2010)

3.10 DATA ANALYSIS

For each participant, a print out from the ultrasound unit was obtained, and the results were then captured by the researcher on an excel spreadsheet for data analysis (Appendix E). The researcher was not blinded to the group allocation. A qualified statistician analyzed the data using IBM SPSS version 20 (IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp). A *p* value <0.05 was used to determine statistical significance. The normality was attained by looking at the mean and SD in the groups and if two times the SD subtracted from the mean is not a negative number or an impossible value then it is plausibly normally

distributed. Independent samples t-tests were used to compare the means of normally distributed variables between the two groups. Pearson's chi square tests were used to compare proportions between the two groups. Intra-group paired t-tests were used to test whether the mean values changed after intervention in each group separately. Repeated measures ANOVA testing was used to compare the change from pre- to post-intervention between the two groups. Profile plots were generated to visually assess the trends of the Mean arterial blood flow and lumen diameter by time and group (Esterhuizen, 2013).

CHAPTER FOUR

RESULTS

4.1 PARTICIPANT CHARACTERISTICS

4.1.1 Gender

Figure 5 demonstrates that there was a statistically significant higher number of males in the moist ice pack group compared to the commercially available cooling cuff group (p = 0.05; Pearson's Chi square = 3.94). Gender was then used as a covariate in the analysis to correct for this imbalance to assess the true difference between the two interventions.

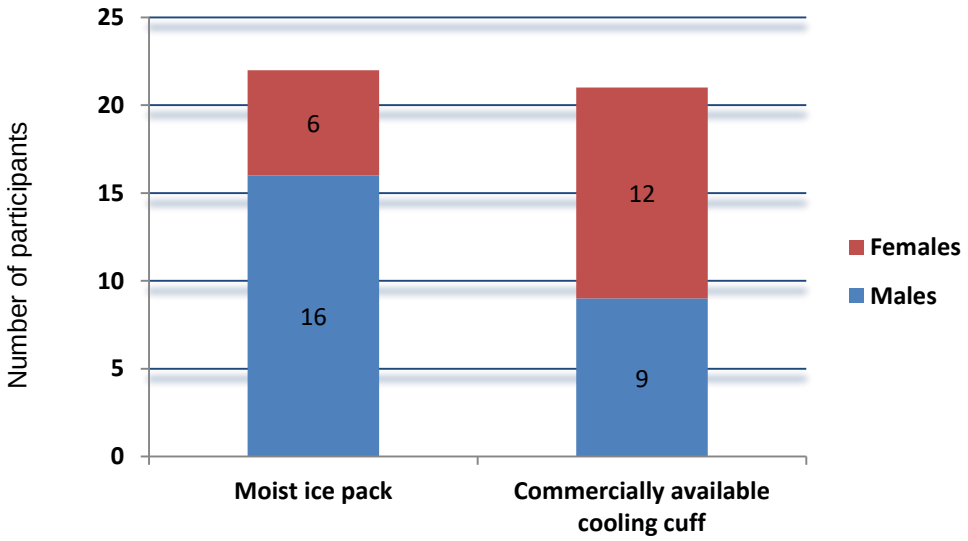

Figure 6: Gender distribution per group (n=43)

4.1.2 Ethnicity

Both groups had a similar number of ethnic participants (Figure 6), in that each group had three black participants but the commercially available cooling cuff group had 18 white participants against 19 white participants in the moist ice pack group.

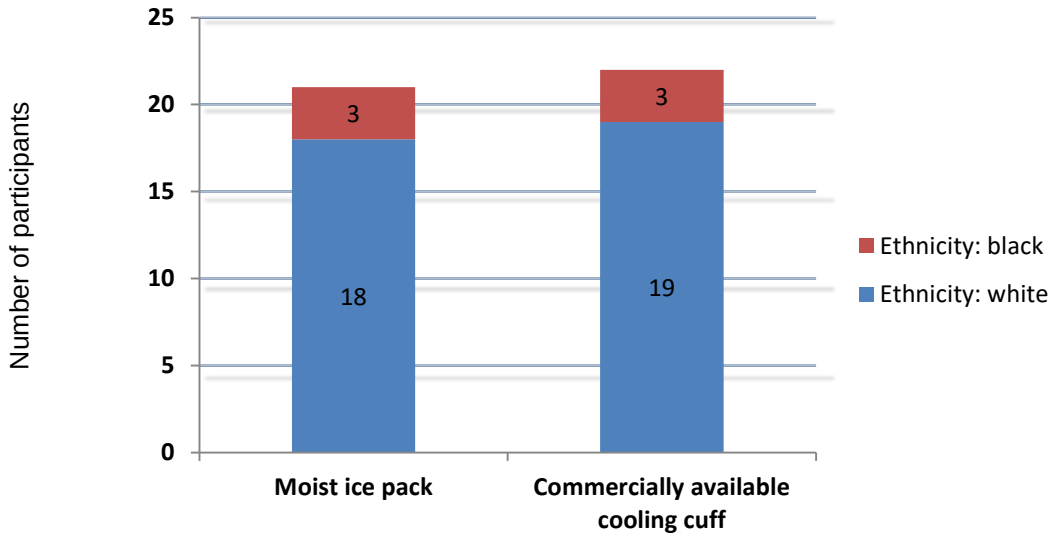

Figure 7: Ethnic distribution per group (n=43)

4.1.3 Age

The age of the participants in the study ranged from 19 to 42 years of age with a mean age of 27.60. There were no statistically significant differences between the two groups in terms of age as demonstrated in Table 1.

Table 1: Mean age (years) of participants by group

Group	n	Mean	Std. Deviation	*p*- value
Moist Ice pack	22	26.59	5.94	0.29
Commercially available cooling cuff	21	28.62	6.70	

(Two sample independent t-test)

4.1.4 Height, Weight and Body Mass Index

There were no statically significant differences in height, weight or body mass index (BMI) between the two groups as depicted in Table 2.

Table 2: Mean height, weight and BMI measurements per group

Category	Group	n	Mean	Std. Deviation	*p*- Value
Height (cm)	**Moist Ice Pack**	22	174.82	10.75	0.97
	Commercially available cooling cuff	21	174.71	7.94	
Weight (kg)	**Moist Ice Pack**	22	84.91	21.53	0.54
	Commercially available cooling cuff	21	80.95	20.22	
BMI ($kg.m^{-2}$)	**Moist ice pack**	22	27.41	4.49	0.51
	Commercially available cooling cuff	21	26.39	5.67	

(Two sample independent t-test)

4.1.5 Blood Pressure

The male and female mean blood pressure reading were 117/76 mmHg and 114/71 mmHg respectively. Table 3 shows that there were no statistically significant differences between the groups in terms of systolic and diastolic blood pressure.

Table 3: Mean systolic and diastolic blood pressure for the two groups

Pressure	Group	n	Mean	Std. Deviation	*p*- Value
Systolic (mmHg)	**Moist Ice pack**	22	119.45	10.21	0.52
	Commercially available cooling cuff	21	117.57	8.79	
Diastolic (mmHg)	**Moist Ice pack**	22	74.45	8.028	0.67
	Commercially available cooling cuff	21	73.48	6.728	

(Two sample independent t-test)

4.2 BASELINE MEASUREMENTS

Table 4 shows that there were no statistically significant differences between the two groups in terms of radial artery lumen diameter and radial artery blood flow. The combined baseline mean blood flow (n=43) was 47.20 $cm.s^{-1}$. The males and females had a mean diameter of 2.62 mm and 2.01 mm respectively.

Table 4: Base line radial artery blood flow and radial artery lumen diameter for the two groups

Radial artery	Group	Mean	Std. Deviation	*p*- Value
Pre-Lumen Diameter (mm)	**Moist ice pack**	2.50	0.50	0.18
	Commercially available cooling cuff	2.20	0.50	
Pre-Arterial Blood Flow ($cm.s^{-1}$)	**Moist ice pack**	47.30	9.50	0.94
	Commercially available cooling cuff	47.00	10.70	

(Sample independent t-test)

4.3 INTRA-GROUP ANALYSIS

4.3.1 Moist Ice pack group

4.3.1.1 Radial artery blood flow

After the application of moist ice, this group showed a statistically significant decrease in arterial blood flow as demonstrated in Table 5.

Table 5: Intra-group analysis of radial artery blood flow for the moist ice pack group

Radial artery	n	Mean	Std. Deviation	p-Value
Pre-Arterial Blood Flow ($cm.s^{-1}$)	22	47.27	9.53	< 0.001
Post-Arterial Blood Flow ($cm.s^{-1}$)	22	41.64	6.86	

(Paired t-test)

4.3.1.2 Radial artery lumen diameter

There were no statistically significant changes to mean radial artery lumen diameter after the application of the moist ice pack as represented in Table 6.

Table 6: Intra-group analysis of radial artery lumen diameter for the moist ice pack group

Radial Artery	n	Mean	Std. Deviation	*p*- Value
Pre-Lumen Diameter (mm)	22	2.45	0.51	0.16
Post-Lumen Diameter (mm)	22	2.36	0.49	

(Paired t-test)

4.3.2 Commercially available Cooling Cuff Group

4.3.2.1 Radial artery blood flow

After the application of the commercial cooling cuff, there was a statistically significant change to the mean arterial blood flow as represented in Table 7.

Table 7: Intra-group analysis of radial artery blood flow for the commercially available cooling cuff group

Radial Artery	n	Mean	Std. Deviation	*p*- Value
Pre-Arterial Blood Flow (cm.s-^{1})	21	47.05	10.66	< 0.001
Post-Arterial Blood Flow (cm.s^{-1})	21	38.90	10.77	

(Paired t-test)

4.3.2.2 Radial artery lumen Diameter

Table 8 shows that there were no statistically significant changes in mean radial artery lumen diameter.

Table 8: Intra-group analysis of radial artery lumen diameter for the commercially cooling cuff group

Radial Artery	n	Mean	Std. Deviation	*p*- Value
Pre-Lumen Diameter (mm)	21	2.24	0.54	1.000
Post-Lumen Diameter (mm)	21	2.24	0.54	

(paired t-test)

4.4 INTER-GROUP ANALYSIS

4.4.1 Radial Artery Blood Flow

There were no statistically significant differences in arterial blood flow (p = 0.81; Repeated measure ANOVA) over time between the two groups as depicted in Figure 7.

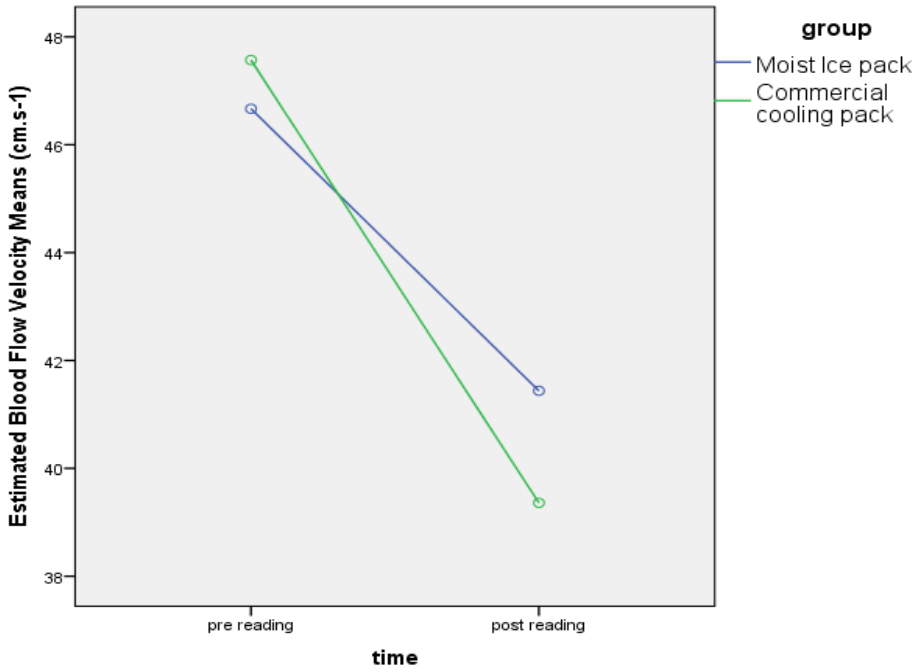

Figure 8: Changes in mean radial artery blood flow (cm.s-^{1})for the two groups over the study period

4.4.2 Radial Artery Lumen Diameter

There were no statistically significant differences in radial artery lumen diameter between the two groups (p = 0.54, repeated measures ANOVA) as shown in Figure 8.

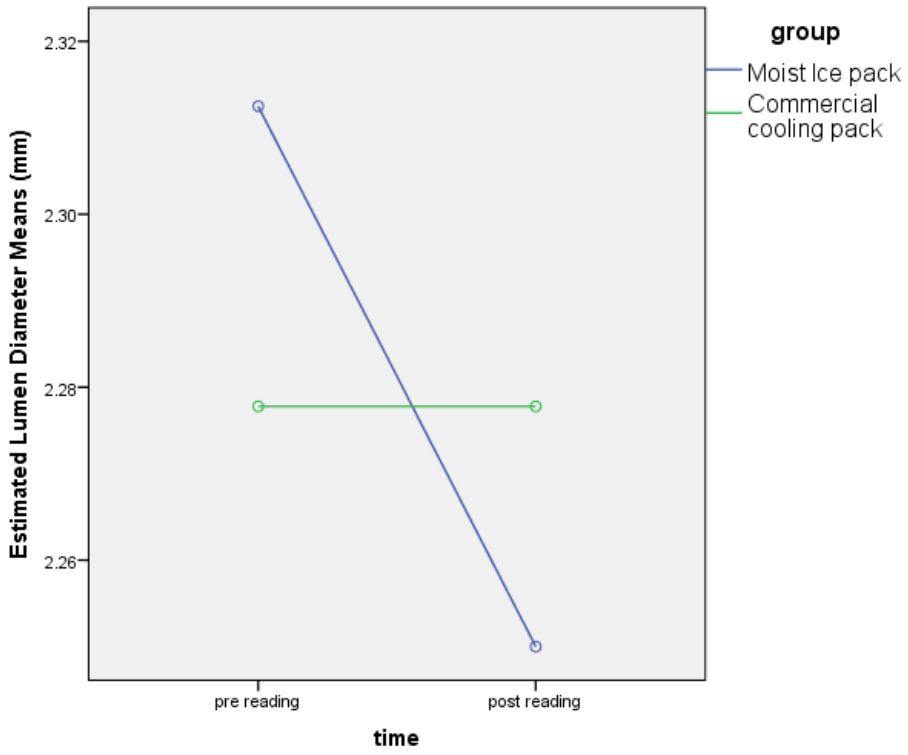

Figure 9: Changes in mean radial artery lumen diameter (mm) of the two groups over the study period

4.5 Adverse effects

None of the participants in the commercially available cooling cuff group reported any adverse effects either during the intervention or after it. The moist ice group experienced mild discomfort towards the end of the 15 mins application which subsided shortly after the removal of the moist ice pack.

CHAPTER FIVE

DISCUSSION

5.1 PARTICIPANTS CHARACTERISTICS

5.1.1 Gender and age

This study was open to both males and females. However, more males participated in the study than females (Figure 5), leading to a statistically significant difference in gender between the two groups. Loh *et al*. (2007) and Huzjan *et al*. (2004) found that males have a greater mean arterial diameter and a greater systolic blood pressure compared to females (Azhim et al., 2007). This was supported by this study (section 4.2 and 4.1.4). During statistical analysis, the gender imbalance was adjusted for so the effect of gender on the results was minimised.

The age of the participants (18-45 years) was pre-selected to limit the influence of cardiovascular disease and natural degenerative changes (Weston *et al*., 1994). Increasing age raises the risk and severity of cardiovascular disease (Lakatta and Levy, 2003). However, with this age range, there were several respondents who were hypertensive (n=7), and therefore had to be excluded from the study. There were no statistically significant differences between the groups in terms of age (Table 1); therefore, the influence of age on the result would have been minimal. However, the results cannot be extrapolated to an older or younger population.

5.1.2 Ethnicity

This study was not confined to a specific ethnic group. The ethnicity between the two groups was very similar with an almost even distribution of black and white participants per group (Section 4.1.3). Loh *et al.* (2007) found that ethnicity influenced the radial artery diameter (Section 2.5). eThekwini is home to a large majority of Indian people, but there were no Indian participants in this study therefore this study does not represent the population of eThekwini .

5.1.3 Height, Weight and Body Mass Index (BMI)

There were no statistically significant differences between the two groups in terms of height, weight and BMI (Table 2). Azhim *et al*. (2007) found in an asymptomatic healthy population (n=50) that participant height did not significantly affect blood pressure but that there was a relationship between being overweight, high blood pressure, and lower blood velocities ($p < 0.05$). It was also found that all blood velocity indices had a significant relationship to height and weight ($p < 0.05$). The participants in this study were classified as overweight (25-29.9) according to the BMI scale (Table 2). BMI does not allow for an accurate measurement of adiposity, since it unable to differentiate between lean body mass from fat (de Gonzalez *et al*., 2010). Although BMI is a well utilised measure of obesity it can overestimate body fat in persons with a great amount of muscular bulk and athletes (National Institutes of Health, 2013). The results of this study cannot be generalised to persons of other BMI categories.

5.1.4 Blood Pressure

There were no statistically significant differences between the groups in terms of blood pressure (Table 3). All participants recruited for the study were required to be healthy and asymptomatic, similar to participants in the study performed by Topp *et al*. (2011). The study inclusion criteria prevented participants from entering the study if they suffered with any cardiovascular disease such as hypertension as it is known to alter arterial diameter (Section 2.5).

5.2 RADIAL ARTERY LUMEN DIAMETER

At baseline there was no statistically significant difference between the two groups in terms of mean radial artery diameter (Table 4). The combined mean radial artery diameter for the two groups was 2.30 mm which was the same mean reported by Shima *et al*. (1996) in Japanese cadavers and similar to the mean (2.34 mm) reported by Ku *et al*. (2006) in a Korean population. This study's mean radial artery diameter was lower than the means reported by Yoon (1998) (2.70 mm) and Yoo *et al.* (2005) (males, 2.69

mm; females, 2.43 mm) in a Chinese population. Both Yoon (1998) and Yoo *et al*. (2005) used patients undergoing a trans-radial coronary procedure with a large variation in the age of the patients. This differs to this study as the participants in this study were all asymptomatic and both groups were similar in age. These results may indicate that that ethnicity may affect the size of the radial artery, however as discussed under section 5.1.2 the ethnicity of the participants in this study was similar between the groups.

After the application of moist ice and the commercially available cooling cuff, there were no statistically significant changes in radial artery lumen diameter within the groups (Table 6 and Table 8) or between the groups (Figure 8). This finding was unexpected as it is reported that cryotherapy techniques result in vasoconstriction (Section 2.11.1). Vasoconstriction happens through either the direct mechanism of the smooth muscle in the arterial walls contracting (Guyton, 1991) or through the indirect mechanism, in which the production of vasodilator mediators decreases (Cameron, 1999). Cryotherapy modalities constrict cutaneous blood vessels (Cameron, 1999; Galeotti *et al*., 2002), which may indicate that the cooling effect only results in vasoconstriction of the cutaneous blood vessels after 15 minutes of cooling and does not affect medium sized arteries (i.e. the radial artery). A similar finding was found by Topp *et al*. (2013) where the radial artery lumen diameter was assessed for changes after the application of a menthol gel and an ice pack and resulted in no change in the radial artery lumen diameter over a 20 minute time period but there was a significant decrease in blood flow. We need to consider that the radial artery diameter at 15 to 20 mins of cryotherapy application is not affected and cryotherapy only affects the cutaneous blood vessels and should be further researched.

5.3 Radial Artery Blood Flow

The combined baseline mean arterial blood flow was 47.20 $cm.s^{-1}$ (Section 4.2), Topp *et al*. (2013) found a mean of 45.40 $cm.s^{-1.}$ Both study populations were healthy asymptomatic individuals and readings were taken on the right radial artery. Both the moist ice pack (Table 5) and the commercially available cooling cuff groups (Table 7)

showed a statistically significant decrease in blood flow (p = < 0.001) on intra-group analysis indicating that both methods of cooling were effective in decreasing blood flow. On inter-group analysis there was no statistically significant difference between the groups indicating that both groups resulted in a similar decrease in blood flow. Thus, the commercially available cooling cuff had an effect on blood flow to a similar extent as the moist ice pack.

It is well documented that ice decreases blood flow following cryotherapy techniques (Abramson *et al*., 1966; Weston *et al.*, 1994; Ho *et al*., 1994; Fiscus *et al*., 2005; Topp *et al.*, 2011; Topp *et al*., 2013). The proposed mechanism is that a neuronal reflex through the spinal pathway results in cutaneous vessel vasoconstriction (Folkow *et al.,* 1963; Faber, 1988; Bailey *et al.*, 2004), which is similar to the mechanism of action of menthol (Galeotti *et al*., 2002 Topp *et al*., 2013). Secondly a reduction in tissue temperature activates a chemical mechanism resulting in cold induced cutaneous blood vessel vasoconstriction with a resultant reduction in blood flow (Bailey *et al.*, 2004). Another factor could be contributed to an increase in the viscosity of blood following the cryotherapy applications which increases the resistance to blood flow which will decrease the velocity of blood flow in the absence of vasoconstriction (Swenson *et al*., 1996).

This result indicates that the commercially available cooling cuff works on a similar physiological mechanism as ice as it resulted in similar changes for both radial artery lumen diameter and blood flow.

5.4 Adverse Effects

There were no adverse effects reported during the study from using the commercially available cooling cuff, indicating that the cooling can be safely utilised for a period of 15 mins. There were no adverse effects during the use of the moist ice pack except for mild discomfort due to the cold intensity. This indicates that the commercially available cooling cuff was more comfortable for participants than the moist ice pack for a duration of 15 mins.

5.5 Hypothesis

The null hypothesis (H_O) is not rejected as there was no statistically significant difference between the radial artery blood flow (cm.s-1) and radial artery lumen diameter (mm) when comparing the commercially available cooling cuff group to the moist ice group after 15 minutes.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This study aimed to compare the effect of moist ice and a commercially available cooling cuff on radial artery blood flow ($cm.s^{-1}$) and radial artery lumen diameter (mm) to assess the effectiveness of the commercially available cooling cuff as a method of cryotherapy. Neither of the cryotherapy applications resulted in a change to radial artery diameter. However, there was a decrease in blood flow when both cryotherapy techniques were applied and results show that there was no statistically significant difference between the groups indicating that they have a similar mechanism of action.

These results support the use of the commercially available cooling cuff as an alternative technique for applying cryotherapy as it alters blood flow over 15 min duration. However, the results reflect poor external validity and should be viewed with caution as this study was conducted on asymptomatic participants when cryotherapy methods are usually applied to symptomatic people.

6.2 RECOMMENDATIONS

Recommendations for future studies:

1) A similar study should be conducted on a larger sample size to determine the generalisability of the results and to further assess potential effect size for blood flow reduction during cryotherapy.

2) The use of a cross-over research design should be utilised as this will strengthen the results of this study.

3) The commercially available cooling cuff should be further investigated for application periods longer than 15 minutes to determine its effect on blood flow and radial artery diameter as the manufacture advocates the cuff to be applied for periods up to 24 hours.

4) The ultrasonographer should be blinded to the groups in future studies to minimise bias.

5) A perceived discomfort intensity scale of treatment should be included to determine which method of cooling is more comfortable for the patient.

6) A similar study should be conducted on a symptomatic group with a closed soft tissue injury, and should include the assessment of nerve conduction.

7) The study should include people with varying complaints (e.g. people with hypertension) and should be undertaken in different environmental conditions (i.e. to mimic field side conditions e.g. varying temperatures and physical activity pre- or during application) to determine if the results vary.

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Appendices

Appendix A

Letter of information and informed consent

Dear Participant

Thank you for showing interest in my research project.

Title of the Research Study: The effect of a commercial cooling cuff and moist ice packs on radial artery blood flow and radial artery lumen diameter

Principle Investigator: Joshua Gernetzky

Co- Investigator: **Supervisor:** Dr. D. Varatharajullu [MTech: Chiropractic]

Co- Supervisor: Dr. L. O'Connor [MTech: Chiropractic, CCEP]

Brief Introduction and Purpose of the Study:
Cryotherapy (therapy that uses cooling to bring about healing) has been used for centuries. The most commonly used cooling therapy is ice, followed by cooling gels. There is a novel product on the market that claims to administer cryotherapy however the company's claims have not been fully investigated. This research study aims to investigate the effect of this commercial cooling cuff versus a moist ice pack on radial artery blood flow and lumenal (the hollow area of the blood vessel through which blood flows) diameter by means of Doppler ultrasonography (a device that measure blood flow by means of sound waves).

Outline of the Procedures:
Fifty participants will be recruited to partake in this study. The group will be divided into two, with 50% having moist ice therapy and the other 50% will receive the cooling cuff. The first consultation will take place at the Chiropractic Day Clinic, Durban University of Technology, you will be given verbal information about the research, and then you will be required to read this letter of information, there after you will have an opportunity to ask questions. If you agree to take part in this research, you will be required to sign an informed consent form. Then, an hour long appointment will commence. The researcher will take a case history and perform a physical examination. This will be done to ensure your suitability for the research. Should you meet the study requirements you will then be assigned to one of the two therapeutic cooling groups.

Depending on the availability of the ultrasonographer, the Doppler ultrasound evaluation may be done on the same day after this appointment or within 5 working days. The second appointment will take place at the Radiography clinic, Durban University of Technology, where you will be met by the researcher. This appointment will take approximately 50 minutes. Please do not consume alcohol or caffeine or performed exercise with in last 24 hours of this appointment. If you do this appointment will have to be re-scheduled. Please arrive at least 10 minutes before this appointment.

You will be introduced to ultrasonographer were you will then be asked to remove any clothing covering the area below the elbow (should they require a clinic gown one will be provided). You will then relax in a chair while the researcher fetches the relevant cooling product. Five minutes before the cooling therapy is applied, measurements using the Doppler ultrasound will be taken. The researcher will then place the cooling therapy on your forearm. After 15 minutes the measurement will be re-taken. Then the cooling therapy will be removed.

Risks or Discomforts to the Subject: There are no risks in partaking in this study, however you may feel burning and/or a numbing sensation due to the application of cold therapy. If this sensation becomes intolerable, please let the researcher know and the cooling therapy will be removed from your arm.

Benefits:
This study will help to determine if the commercial cooling cuff is effective in changing arterial blood blow.

Reason/s why the Subject May withdraw from the study: You are free to withdraw from this study at any stage without any negative repercussions.

Remuneration:
You will not be offered any form of remuneration for taking part in the study.

Costs of the Study: The initial consultation and the Doppler ultrasound evaluation are free of charge.

Confidentiality:
All research records will be kept confidential and will be stored in the Chiropractic Programme for 15 years, after which it will be shredded. Your name will not appear on any of the data sheets or in the dissertation.

Research-related injury: There will be no compensation in the event of an injury.

Persons to Contact in the Event of Any Problems or Queries:

Please contact me (031 373 2205), my supervisor Dr. D. Varatharajullu (031 373 2923), or the Institutional Research Ethics Committee Administration (031 373 2900). Complaints can be reported to the DVC: TIP, Prof F. Otieno on 031 373 2382 or dvctip@dut.ac.za.

Yours sincerely,

J. Gernetzky

INSTITUTIONAL RESEARCH ETHICS COMMITTEE (IREC)
CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, _____ (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _____,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

_____	_____	_____	_____
Full Name of Participant	**Date**	**Time**	**Signature / Right Thumbprint**

I, _____ (name of researcher) herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

_____	_____	_____
Full Name of Researcher	**Date**	**Signature**
_____	_____	_____
Full Name of Witness (If applicable)	**Date**	**Signature**
_____	_____	_____
Full Name of Legal Guardian (If applicable)	**Date**	**Signature**

Appendix B

CHIROPRACTIC PROGRAMME

CHIROPRACTIC DAY CLINIC

CASE HISTORY

Patient:_____ Date:_____

File #: _____ Age: _____

Sex: _____ Occupation: _____

Student:_____ Signature _____

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature:

Case History:

Examination:

Previous: Current:

X-Ray Studies:

Previous: Current:

Clinical Path. lab:

Previous: Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL: Reason for Conditional:
Signature: Date:

Conditions met in Visit No:	Signed into PTT:	Date:

Case Summary signed off:	Date:

Student's Case History:

1. Source of History:

2. Chief Complaint: (patient's own words):

3. Present Illness:

	Complaint 1(principle complaint)	Complaint 2 (additional or secondary complaint)
Location Onset : Initial: Recent: Cause: Duration Frequency Pain (Character) Progression Aggravating Factors Relieving Factors Associated S & S Previous Occurrences Past Treatment Outcome:		

4. Other Complaints:

5. Past Medical History:

General Health Status

Childhood Illnesses

Adult Illnesses

Psychiatric Illnesses

Accidents/Injuries

Surgery

Hospitalizations

6. Current health status and life-style:

Allergies

Immunizations

Screening Tests incl. x-rays

Environmental Hazards (Home, School, Work)

Exercise and Leisure

Sleep Patterns

Diet

Current Medication

Analgesics/week:

Other (please list):

Tobacco

Alcohol

Social Drugs

7. Immediate Family Medical History:

Age of all family members

Health of all family members

Cause of Death of any family members

	Noted	Family member		Noted	Family member
Alcoholism			Headaches		
Anaemia			Heart Disease		
Arthritis			Kidney Disease		
CA			Mental Illness		
DM			Stroke		
Drug Addiction			Thyroid Disease		
Epilepsy			TB		
Other (list)					

8. Psychosocial history:

Home Situation and daily life

Important experiences

Religious Beliefs

9. **Review of Systems** (please highlight with an asterisk those areas that are a problem for the patient and require further investigation)

General

Skin

Head

Eyes

Ears

Nose/Sinuses

Mouth/Throat

Neck

Breasts

Respiratory

Cardiac

Gastro-intestinal

Urinary

Genital

Vascular

Musculoskeletal

Neurologic

Haematological

Endocrine

Psychiatric

Appendix C

ELBOW REGIONAL EXAMINATION

Patient: _____ File No.: _____ Date: _____
Intern / Resident: _____ Signature: _____
Clinician: _____ Signature: _____

OBSERVATION:

- Posture and willingness to move _____
- Carrying angle (anatomical position) _____
- Colour and texture of skin _____
- Bony and soft tissue contours _____
- Swelling _____
- Position of function (triangle sign) _____

PALPATION:

Anterior :

- Cubital fossa _____
- Bicep tendon _____
- Brachial artery _____
- Coronoid process _____
- Radial head _____
- Bicep and Brachialis _____

Medial:

- Medial epicondyle _____
- Medial collateral ligament _____
- Ulnar nerve _____

Lateral:

- Lateral epicondyle _____
- Supracondylar ridge (ECRL) _____
- Lateral collateral ligament _____
- Radial head and annular ligament _____

Posterior:

- Olecranon process _____

ACTIVE MOVEMENTS:

- Flexion (140 – 150°) _____
- Extension (0-10°) _____
- Supination (90°) _____
- Pronation (80-90°) _____

PASSIVE MOVEMENTS:

- Flexion (tissue approximation) _____
- Extension (bone to bone) _____
- Supination (tissue stretch) _____
- Pronation (tissue stretch) _____

RESISTED ISOMETRIC MOVEMENTS: (elbow at 90° flexion and supinated)

- Flexion _____
- Extension _____
- Supination _____
- Pronation _____
- Elbow flexion _____
- Elbow extension _____

JOINT PLAY MOVEMENTS:

- Upward glide of radial head on ulna _____
- Downward glide of radial head on ulna _____
- Rotation of radial head _____
- Medial to lateral side tilt _____
- Lateral to medial side tilt _____
- Distraction of olecranon process on the humerus (90° flexion) _____

SPECIAL TESTS:

- Ligamentous Instability Test:
  - valgus / adduction stress (MCL) _____
  - varus / abduction stress (LCL) _____
- Lateral epicondylitis:
  - Cozen's Test _____
  - Mill's Test _____
  - Lateral epicondyle test (extensor digitorum) _____
- Medial epicondyle test _____
- Tinel's Sign (ulnar nerve) _____
- Wartenberg's Sign (ulnar neuritis) _____
- Elbow flexion test (ulnar nerve - cubital tunnel syndrome) _____
- Pronator teres syndrome test (median nerve) _____
- Pinch Grip test (ant. interosseous branch of median nerve) _____

NEUROLOGICAL:

- Reflexes
  - Biceps (C5/6) R _____ L _____
  - Brachioradialis (C5/6) R _____ L _____
  - Triceps (C7/8) R _____ L _____
- Dermatomes C4 _____ C5 _____ C6 _____ C7 _____ C8 _____
  T1 _____ T2 _____
- Cutaneous distribution
  - median nerve _____
  - ulnar nerve _____
  - radial nerve _____

RADIOLOGICAL EXAMINATION:

_____
_____
_____

DIAGNOSIS:

_____
_____
_____

MANAGEMENT PLAN:

_____
_____
_____

Appendix D

CHIROPRACTIC PROGRAMME

PHYSICAL EXAMINATION: SENIOR

Patient Name: _____ **File no:**				**Date:**	
Student: **Signature:**					
VITALS:					
Pulse rate:			Respiratory rate:		
Blood pressure:	R	L	Medication if hypertensive:		
Temperature:			Height:		
Weight:	Any recent change?	Y / N	If Yes: How much gain/loss	Over what period	
GENERAL EXAMINATION:					
General Impression					
Skin					
Jaundice					
Pallor					
Clubbing					
Cyanosis (Central/Peripheral)					
Oedema					
Lymph nodes	Head and neck				
	Axillary				
	Epitrochlear				
	Inguinal				
Pulses					

Urinalysis	
SYSTEM SPECIFIC EXAMINATION:	
CARDIOVASCULAR EXAMINATION	
RESPIRATORY EXAMINATION	
ABDOMINAL EXAMINATION	
NEUROLOGICAL EXAMINATION	
1.1.1 COMMENTS	
Clinician: **Signature:**	

Appendix E

Group 1: Moist ice pack											
	Baseline reading:		15 minute reading:		Age	Sex	Height	Weight	Systolic	Diastolic
	Lumenal diameter (mm)	Arterial blood flow (cm.s-1)	Lumenal diameter (mm)	Arterial blood flow (cm.s-1)						
Participant:										

Group 2: Recoolx cooling cuff										
	Baseline reading:		15 minute reading:		Age	Sex	Height	Weight	Systolic	Diastolic
	Lumenal diameter (mm)	Arterial blood flow (cm.s-1)	Lumenal diameter (mm)	Arterial blood flow (cm.s-1)						
Participant:										

Appendix F

Durban University of Technology

Memorandum of understanding between:

The RESEARCH INSTITUTION'-Durban University of Technology (this includes the respective research student and research supervisor, Department of Chiropractic. The Faculty of Health Sciences Research Committee, The Institutional Research Committee and any other related DUT employees.

AND
The 'MANUFACTURER'- Commercial cooling wrap (including all members, employees, associates)

This Memorandum of Understanding pertains to the following research project and must be read in conjunction with:
APPENDIX A-Detailed Research Proposal (PG4a)
APPENDIX B-Durban University of Technology Research Committee Research Ethics Policy and Guidelines

Title of the study:
The effect of a cooling cuff and moist ice pack on radial artery blood flow and lumen diameter.

Research Supervisor: Dr D. Varatharajullu (Dept. Chiropractic and Somatology-Durban University of Technology)

This study is a Master's Mini Dissertation conducted in partial compliance with the Master's Degree in Technology in the Department of Chiropractic-Faculty of Health Sciences-Durban University of Technology. This study will obtain ethical approval from the Faculty of Health Sciences Research & Ethics Committee (FRC) of Durban University of Technology.

Please be aware the brand name will not be divulged to the participants and not included in any of the letters of information as well as the dissertation.

Section 1-Funding of the study and financial commitment

1.1 A research allowance of R5000.00 has been awarded by the Dept. Post-graduate Development & Support –The details of the funds approved are described in Section A of the Research Proposal (PG4a) attached.

1.2 The 'MANUFACTURER'-will donate (free of charge) the respective experimental cooling cuffs in quantities sufficient to meet the requirements described in the research proposal PG4a attached and contribute to paying the statistician.

1.3 The 'MANUFACTURER'-acknowledges that THE RESEARCH INSTITUTION' will have no financial obligations or commitments to the 'MANUFACTURER' what so ever as a result of conducting this study.

1.4 The 'MANUFACTURER'-(with the exception of Section 1.2) may not award or incentivize the study or its related parties in any manner what so ever, nor remunerate, award or offer any financial or other donation or gift to any of those involved with the study.

Section 2-Academic processes and outcome

2.1 The FRC has approved the above mentioned Research Supervisor who in conjunction with the Research Student are the sole contributors to the academic content, procedures, results and findings of the study based on the prescribed data analysis in the research

proposal, barring amendments required by the approved research examiners appointed by the RESEARCH INSTITUTION.

2.2 The 'MANUFACTURER' acknowledges that the findings upon completion of the study (as determined by the Research Student and Research Supervisors and according to the protocol stated in the attached research proposal) will be final and non-negotiable. The 'MANUFACTURER'-acknowledges further that it has no authority over the outcome of this study and may not influence the findings or the reporting thereof in any matter.

2.3 Any modification or deviation from the approved research proposal, must be applied for in writing, endorsed by both the Research Student & Supervisors and Head of Department before serving before the FRC/IREC, the final say therein will be determined by the FRC/IREC.

2.4 The 'MANUFACTURER'-acknowledges that it may not influence or make any change to the approved research protocol/proposal.

Section 3-Publication of findings

3.1 The findings and outcome of the above mentioned study remain the intellectual property of the 'RESEARCH INSTITUTION' indefinitely. The study will be published in the format of a hard bound dissertation which will be placed in the DUT library.

3.2 Publication of the findings of this study in a journal or other scholarly medium will be at the discretion of the Research student and /or Research Supervisors who will determine the appropriate medium and place of publication as well as content of the publication. Authorship of any scholarly output originating from this study of the Research Student and Research Supervisors and other collaborators appointed by the Research Student and/or the Research Supervisors. Such scholarly publication must include the names of the Researcher and the Research Supervisor as well as the 'RESEACH INSTITUTION'.

3.3 Any reference what so ever to the findings of this study if quoted or mentioned in any format must make formal reference to the respective dissertation its official title and its author(s) and the owners of the intellectual property thereof i.e. the 'RESEARCH INSTITUTION'.

3.4 Any reference what so ever to any secondary publication arising from this original study must make formal reference to the respective dissertation its official title and its author(s) and the owners of the intellectual property thereof i.e. the 'RESEARCH INSTITUTION'

3.5 The 'MANUFACTURER'-may make reference to the outcome of this study in the prescribed manner mentioned in section 3.3 and 3.4 undertaking 3.1 and 3.2.

Section 4-Indemnity

4.1 The Research Student, the Research Supervisor and the research facilities and its staff are duly covered by the 'RESEARCH INSTITUTION' insurance policy pertaining to public liability, injury or harm which may occur as a result of conducting this study.

4.2 The 'MANUFACTURER'-undertakes to indemnify the 'RESEARCH INSTITUTION' with regard to any outcome, incidents, injury or harm which occurs as a result of the conduction of this study including the results of the study and publication thereof.

Section 5

5.1 Ethical clearance of the proposed study will be granted by the DUT IREC (such ethical clearance become invalid should there be any deviation from the approved research methodology described in the research proposal attached).

5.2 The 'MANUFACTURER' undertakes to abide by the DUT Research Committee Research Ethics Policy and Guidelines (APPENDIX B).

5.3 In addition to 5.2 the 'MANUFACTURER should note and refer to **Section 1.4,2 & 3** of this document.

I [redacted] **(name of representative of the 'MANUFACTURER')** hereby in my official capacity as representative of the commercial cooling wrap hereby agree to abide by the regulations stated in this memorandum of understanding between the 'MANUFACTURER' and the 'RESEARCH INSTITUTION'

[redacted]

Signature of official representative of the 'MANUFACTURER'

2013-07-28

Date

I **Mr. Joshua Gernetzky** hereby in my capacity as **the research student** hereby agree to abide by the regulations in this memorandum of understanding between the 'MANUFACTURER' and the 'RESEARCH INSTITUTION'

[redacted]

Signature of research Student

2013-08-01

Date

Appendix G

DUT DURBAN UNIVERSITY OF TECHNOLOGY

Department of Radiography

Memo

To: Joshua Gernetsky
Chiropractic Student

From: Mrs S Naidoo
HOD: Radiography

Date: February 11, 2013

RE: Cost- Ultrasound examinations

Dear Mr Gernetsky,

Ms C Dludla (Lecturer/ultrasonographer) in the department of Radiography will perform the ultrasound scans for the fifty patients which are part of your research. It is envisioned (noted from previous experience) that it will take 30 minutes to complete each patient. Hence the total cost to scan all the patients will be R2500 (R50 X 50 patients).

Yours truly

Mrs S Naidoo (Head of Department: Radiography)

Faculty of Health Sciences Ritson Road Campus, Durban University of Technology.

P O.Box 1334

Durban 4001
Tel: 27 31 3732875/2450
Fax: 27 31 3732574
Email: nalenen@dut.ac.za

Appendix H

RESEARCH!!!!!

A new cooling product is being carried out at Durban University of Technology.

Please call for more information if you are between 18 and 45 years of age…

Your help is valued…

Researcher: Joshua

Call: 0828880630

Place: Durban University of Technology Chiropractic Day clinic.

Please call if you are healthy and to see if you qualify to take part in this trial

Appendix I

I _____ herby grant Joshua Gernetzky the researcher to distribute flyers and posters around our premises_____ with regards to the research being carried out at Durban University of Technology Chiropractic Day Clinic.

Date:_____

Full name: _____ Position:_____ Signature:_____

Researcher: Joshua Gernetzky

_____

Appendix J

Letter of information and informed consent

This is a pilot study for the Research Study:
The effect of a commercially available cooling cuff and moist ice packs on radial artery blood flow and radial artery lumen diameter

Principle Investigator: Joshua Gernetzky

Co- Investigator: Supervisor: Dr. D. Varatharajullu [MTech: Chiropractic]

Co- Supervisor: Dr. L. O'Connor [MTech: Chiropractic, CCEP]

Brief Introduction and Purpose of the Study:
This pilot study aims to investigate the effect of a commercially available cooling cuff and a moist ice pack on radial artery blood flow and lumenal (the hollow area of the blood vessel through which blood flows) diameter by means of Doppler ultrasonography (a device that measure blood flow by means of sound waves). To determine the amount of participants it will require for the research to take place. 8 people will be required to complete this study.

Outline of the Procedures:
At the first consultation you will read this information sheet and ask any questions about the research. If you agree to take part in this research, you will have to sign an informed consent form. You will then be assigned to one of the two therapeutic cooling groups. Please do not take any alcohol, caffeine-containing products and medication or take part in any exercise for at least 24 hours before your second appointment.

Risks or Discomforts to the Subject:
There are no risks. If you are in the moist cold group you may feel a burning and/or numbing sensation where the moist ice pack is being applied.

Benefits:
This study will help to determine if the commercially available cooling cuff is effective in changing arterial blood blow.

Reason/s why the Subject May withdraw from the study:
You are free to withdraw from this study at any stage without any negative repercussions.

Remuneration:
You will not be offered any form of remuneration for taking part in the study.

Costs of the Study:
The Doppler ultrasound evaluation are free of charge.

Confidentiality:
Your name will not appear on any of the data sheets or thesis.
Please don't hesitate to ask questions on any aspect of this study. Should you have any complaints or queries, please do not hesitate to contact my research supervisor at the above details or the Constitutional Research Ethics Committee Administration: 031 373 2900
Yours sincerely,

Research-related injury:
There will be no compensation in the event of an injury.

Persons to contact in the Event of Any Problems or Queries:

Head of Department: Dr. A. Docrat, **Contact number:** 031 373 2589

Supervisor: Dr. L. O'Connor, **Contact number:** 031 373 2923

Co- supervisor: Dr. D. Varatharajullu**, Contact number:** 031 373 2094

Statement of Agreement to Participate in the Research Study:

I, subject's full name……....., ID number……, have read this document in its entirety and understand its contents. Where I have had any questions or queries, there have been explained to me by…… to my satisfaction. Furthermore, I fully understand that I may withdraw from this study at any stage without any adverse consequences and my future health care will not be compromised. I, therefore, voluntarily agree to participate in this study.

Subject's name (print) …….. subject's signature:……
Date:……

Researcher's name (print)…….. signature:……
Date:……

Witness name (print)…….. Signature……
Date:……

DURBAN UNIVERSITY of TECHNOLOGY

INSTITUTIONAL RESEARCH ETHICS COMMITTEE (IREC)

20 June 2013

IREC Reference Number: **REC 31/13**

Mr J Gernetzky
18 Alfred Road
Vincent
5247

Dear Mr Gernetzky

The effect of a cooling cuff and moist ice pack on radial artery blood flow and lumen diameter

I am pleased to inform you that Full Approval has been granted to your proposal REC 34/13, subject to the following:

1. Student mentions that IT office was consulted regarding MOU and that they were in agreement – need to provide proof of such agreement
2. Student mentions that a letter will be sent to the manufacturers indicating that their name will not appear in the dissertation or proposal, they will need to sign this and it will be placed as an addendum to the MOU.
3. Still discrepancies between title in MOU and the PG4 – please correct.
4. Under ethical considerations still refers to storage as 5 years instead of 15. Please correct.
5. Appendix F not labelled.
6. Spelling p.8: underlined paragraph change temperate to temperature

The Proposal has been allocated the following Ethical Clearance number IREC 049/13. Please use this number in all communication with this office.

Approval has been granted for a period of one year, before the expiry of which you are required to apply for safety monitoring and annual recertification. Please use the Safety Monitoring and Annual Recertification Report form which can be found in the Standard Operating Procedures [SOP's] of the IREC. This form must be submitted to the IREC at least 3 months before the ethics approval for the study expires.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's. In addition, you will be responsible to ensure gatekeeper permission.

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.