RESEARCH ARTICLE

A comparison of moist heat, dry heat, chemical dry heat and icy hot for deep tissue heating and changes in tissue blood flow.

Authors
J Petrofsky, M Laymon, R Donatelli

Affiliations
Touro University Nevada, Henderson, NV

Correspondence
Jerrold Scott Petrofsky, PhD
Department of Physical Therapy, Touro University, 874 American Pacific Dr Henderson, NV 89014
Telephone: (714) 3215424
E-mail: jpetrofsky@outlook.com

Authors' contributions:

i. Concept and design: jp
ii. Administrative support: all authors
iii. Provision of study materials: jp,ml
iv. Collection and assembly of data: all authors
v. Data analysis and interpretations: jp
vi. Manuscript writing: all authors
vii. Final approval of manuscript: All authors

Abstract

Background: Intermittent bouts of heavy activity at greater than normal exercise intensity can cause delayed onset muscle soreness (DOMS). Several products are commercially available, all alleging to reduce DOMS. In the present investigation, 40 subjects (average age 27.0+/-4.4 years, average BMI 26.8) were assessed to determine the effect of 4 of these products on skin and muscle temperature and blood flow during 2 hours of application. These included ThermaCare Dry Heat Wraps, ThermaCare Moist Heat Wraps, Icy Hot Patches, and hydrocollator heat packs.

Methods; Blood flow was measured (by laser doppler flow meter) over and in the quadriceps muscle and tissue temperature was measured (by thermistors and thermocouples) in these same areas.

Results: The results of the study indicated that only ThermaCare Dry and Moist Heat Wraps both heated the muscle and increased muscle blood flow. The menthol and methyl salicylate compounds in Icy Hot cooled muscle. Skin blood flow increased 300% after the moist heat was applied after 45 minutes, low level continuous dry heat almost 256% but it took 105 minutes to reach this flow, hydrocollator heat wraps increased by 201% but only for only first 45 minutes and then back to baseline, a slight reduction in skin blood flow was seen with Icy Hot gel applied to the skin. Moist heat caused muscle temperature to increase by an average of 3.1 Deg C. Dry heat caused muscle temperature to increase by 2.2 Deg C, while hydrocollator packs increased temperature by 0.4 Deg C. Icy hot had no effect on muscle temperature.

Conclusion: Continuous low level heat products had better penetration into muscle and increased blood flow the best compared to hydrocollator heat packs and Icy Hot patches.

Keywords; skin temperature, muscle blood flow, skin blood flow, heat

1. Introduction

Delayed onset muscle soreness (DOMS) is a clinical symptom of muscle damage consisting of muscular dull, diffuse pain and tenderness and swelling [1] . The symptoms peak at 24 to 48 hours after an exercise session in most people[2-4]. It can occur in an athlete if exercise is suddenly increased or it is typical for heavy physical activity after a person sits all week and then overdoes exercise on the weekend [5]. Eccentric loading causes more muscle damage than concentric loading[6]. Normally, muscle damage stimulates the Satellite cell or stem cell which then stimulates the muscle nucleus to heal. But if severe enough, eccentric loading will produce DOMS[6,7]. The duration of the pain typically is 1-4 days depending on the damage to the tissue[1,8-10]. Recent research is beginning to shed light on the mechanism of DOMS.

Delayed onset muscle soreness is associated with an elevation in plasma concentrations of HSP 27, 40 and interleukin 6, TNF alpha and interleukin 10, all of which are plasma biomarkers of muscle damage. The damage is believed to be due to phagocytosis of muscle tissue by neutrophils and macrophages, and/or increased intramuscular pressure-sensitizing perceptions of pain through group III and IV afferent nerve fibers[11]. Histamine from damaged muscle increases capillary permeability and thus allows for the infiltration of water and white blood cells into the tissue. The increased intramuscular pressure alone can increase pain by activating type III and IV sensory muscle afferents. The release of histamine from damaged muscle further sensitizes H1 and H2 receptors on Type III and type IV nerves fibers in muscle by lowering the activation threshold of these nerves[12-14]. A variety of clinical modalities have been used to alleviate the symptoms of DOMS. Ingestion of branched chain amino acids has been shown to reduce DOMS in older people and people with diabetes [15,16]. Many other strategies have also been tried[17]. The most common strategies involve thermal modalities or massage [17,18]. Vibration has also been used to reduce DOMS[19]. But the most common modality used to reduce DOMS is heat and cold [17,18,20].

Continuous low level heat therapy has been shown to reduce soreness and the concentration of the blood born inflammatory cytokines[18]. Thus, either local heat or warm water hydrotherapy both reduce cytokine concentrations in the blood and reduce pain from delayed onset muscle soreness[21,22]. Heat applied immediately after exercise can increase muscle blood flow and significantly reduce the intensity and duration of DOMS. Heat applied for 8 hours with low level heat wraps immediately after or 24 hours after exercise reduced delayed-onset muscle soreness (DOMS) as well as the typical loss in muscle strength[2] [3,4,23]. Generally, this differs from standard therapeutic modalities such as hydrocollator heat wraps or diathermy or whirlpool heating, all of which are applied for less than 30 minutes [4]. The advantage of ThermaCare heat wraps is that they slowly raise internal tissue temperatures and maintain the temperature for hours. Heat increases metabolism in tissues[4]. This should cause healing to occur more quickly [23,24]. Another benefit of heat is that it reduces pain [25]. In this study, heat reduced muscle stiffness, muscle blood flow and caused less

reduction in muscle strength and less pressure sensitivity.

Heat can be applied to the body in different ways. These include low level heat packs[18] or techniques that warm tissue such as diathermy and ultrasound[26-28]. Heat packs can be dry or moist. Hydrocollator heat packs are usually at 74 deg C and are separated from the skin by 6-8 layers of towels and used only in clinical settings [29]. Hydrotherapy (warm) uses water at 40.5 deg C and involves immersing a limb in the water. Hydrotherapy can include contrast baths or simply warm water immersion[29]. A major problem with this type of heating is that it is usually used for short periods of time, e.g. 5-20 minutes. Moist heat, in most studies, appears to be more advantageous in pain relief to many short duration dry heat modalities[30,31]. But all of these heat modalities are used for short periods of time, e.g., 20 minutes maximum. Many studies show that short duration of heat results in poor heat transfer to deep tissues[29,31-34]. Other factors also alter heat transfer to deep tissues. These include ageing, diabetes, skin blood flow and skin moisture[23,33,35,36]. If body fat, for example can alter heat transfer to deep tissue, then do these modalities really increase muscle temperature and blood flow or are they just analgesic on superficial receptors.

The present investigation is a follow up to a prior pilot study published on 5 subjects[37]. In this study we compared icy hot to ThermaCare dry heat wraps only. Here we expanded this study to 10 subjects in each group examining a common heat source, hydrocollator heat packs compared to low level continuous dry heat (ThermaCare) and moist heat (ThermaCare) and Icy Hot patches. Hydrocollator heat packs are very common in clinical use whereas ThermaCare continuous low level heat wraps are the most common form of Home heat therapy.

2. Subjects

There was a total of forty subjects in this study. Subjects were male and female with a normal BMI. The age, height and weights are listed in Table 1, 2, 3, and 4 below. There was no statistical difference in the age, height and weight or subcutaneous fat thickness between the groups. The average age was 27+/- 4.4 years, average BMI 26.8.

Table 1- Demographics of the subjects in the Icy Hot group

	Age (years	height (cm)	weight (kg)	sub fat thickness (cm)
mean	27.1	175.2	82.1	0.23
sd	4.6	15.4	22.4	0.12

Table 2- Demographics of the subjects in the dry heat (ThermaCare) group

	Age (years	height (cm)	weight (kg)	sub fat thickness (cm)
mean	26.8	174.1	84.2	0.24
sd	4.1	13.5	20.1	0.11

Table 3- Demographics of the subjects in the moist heat (ThermaCare) group

	Age (years	height (cm)	weight (kg)	sub fat thickness (cm)
mean	28.3	177.2	81.1	0.28
sd	5.1	12.2	16.3	0.08

Table 4- Demographics of the subjects in the moist heat (hydrocollator) group

	Age (years	height (cm)	weight (kg)	sub fat thickness (cm)
mean	25.8	173.7	81.4	0.24
sd	3.9	14.1	16.2	0.09

All subjects were free of diagnosed cardiovascular disease, neurological injuries or orthopedic injuries. Subjects were not taking any type of beta agonist or antagonists, or alpha agonists or antagonists. Individuals with hypertension (maximum blood pressure 145/90 mmHg) were excluded. Subjects were also excluded if they were hypotensive (blood pressure less than 90/50 mmHg). Subjects did not have a diagnosed circulatory impairment disease such as Raynaud's disease. All protocols and procedures were approved by the Institutional Review Board of Loma Linda University or Azusa Pacific University and all subjects signed a statement of informed consent.

3. Methods

3.1 Measurement of skin temperature

Skin temperature was measured with a thermistor (SKT RX 202A) manufactured by BioPac systems (BioPac Inc., Goleta, CA). The thermistor output was sensed by an SKT 100 thermistor amplifier (BioPac Inc., Goleta, CA). The output, which was a voltage between 0 and 10 volts, was then sampled with an analog to digital converter at a frequency of a 1,000 samples per second with a resolution of 24 bits with a BioPac MP150 analog to digital converter. The converted data was then stored on a desk top computer using Acknowledge 4.1 software

for future analysis. Data analysis was done over a 5 second period for mean temperature. The temperature was calibrated at the beginning of each day by placing the thermistors used in the study in a controlled temperature water bath which was calibrated against a standard thermometer.

3.2 Measurement of Muscle Temperature:

Deep muscle temperature was measured with a type T thermocouple probe (IT-18), produced by Physiotemp Instruments Inc. 154 Huron Avenue, Clifton NJ, 07013. The devices were 24 gauge thermocouples with a time constant of 0.3 seconds. They were designed as a catheter to be inserted into tissue within the barrel of a 21 gauge needle. The output of the thermocouple was transduced by an IsoThermix digital thermometer system. The device is accurate to 0.1 % and is medically rated with proper RF isolation to minimize risk to subjects. The manufacturer is Columbus Instruments, Columbus, Ohio.

To assure sterility, the wires and assembly were sterilized with Cydex plus for 10 hours prior to use, then washed in sterile saline. In preparation for inserting a catheter into a subject, the skin over the belly of the quadriceps (vastus lateralus) was shaved, cleaned with alcohol and scrubbed with a gauze pad. Next, betadine was placed in a 1 cm ring over the belly of the muscle (motor point). The needle containing the catheter was then inserted into the muscle to a depth of 2.5 cm. The position and depth of the catheter inside the quadriceps muscle was verified by ultrasound (Sonosite 180, Seattle Washington).

Once the thermocouple was appropriately positioned, the needle was gently removed leaving the catheter in place. A drop of collodion (Fisher Scientific, Saint Louis, Missouri) was placed over the catheter insertion as a barrier and the catheter line was taped 10 cm away to prevent it from moving. The catheter was left in place for the duration of the two-hour study.

3.3 Measurement of Central Core Temperature:

Central Core Temperature was determined as tympanic temperature, measured using an infrared thermometer (Braun Type, Thermoscan Type 6022)

3.4 Measurement of Skin Blood Flow:

Skin blood flow was measured with a Moor Laser Doppler flow meter (VMS LDF20, Oxford England). The imager uses a red laser beam (632.8 nm) to measure skin blood flow using the Doppler Effect. After warming the laser for 15 to 30 minutes prior to use, the laser was applied to the skin through a fiber optic probe placed above the vastus lateralis muscle. The probe was a VP12B. The Moor Laser Doppler flow meter measures blood flow through most of the dermal layer of the skin but does penetrate the entire dermal layer. Blood flow is then calculated in a unit called Flux based on the red cell concentration in red cell velocity with a stated accuracy of +/-10%. The tissue thickness sampled is typically 1mm in depth.

3.5 Measurement of Muscle Blood Flow:

Muscle blood flow was measured by a Laser Doppler Flow meter. The Laser

Doppler is produced by Moor Instruments, Oxford, England and marketed by BioPac, Goleta California. The heart of the instrument is an infrared laser probe which samples blood flow in muscle through an implantable fiber with an area of 1 mm^2. The laser beam is very low level and is transmitted into muscle through a fiber optic plastic catheter. This catheter is designed for delivery to deep tissue through the barrel of a 21-gauge needle, just as for the temperature probe described above.

3.6 Measurement of Subcutaneous Fat Thickness:

Subcutaneous fat thickness was measured on the quadriceps muscle of each subject, by ultrasound imagery using a Sonosite 180 plus (Seattle, WA). A L38 linear probe was used at a frequency of 10 MHz. The probe uses 128 elements and has a resolution of greater than 0.5 mm.

3.7 Continuous low-level heat:

ThermaCare Red Box heat wraps were applied to the quadriceps muscle for 120 minutes as per manufacturer's instructions. The ThermaCare heat wrap is a low-level chemical heat wrap whose temperature never exceeds 41 deg C. skin temperature. It is produced by Pfizer Pharmaceuticals, Madison, NJ, USA. The wrap used was for the lower back.

3.8 Icy Hot Patch-

The Icy Hot Patch is OTC and is composed of 5% Menthol in a cotton patch. The manufacturer claims it is a pain-relieving ointment on a (breathable) adhesive pad for up to 8 hours of use. It was also applied over the quadriceps muscle. (Lead Chemical LTD, London, England.)

3.9 Chemical Moist heat-

Moist heat was applied by chemical or non-chemical heat. Chemical moist heat was from a chemical rection involving iron and Brine which then mixed with oxygen and produced heat. Moist pads in the same pack were heated to produce steam which was cooled to 40 deg C by channels in the pack. The pack was manufactured by Pfizer Pharmaceuticals, Madison NJ USA.

3.10 Hydrocollator heat wraps-

Hydrocollator heat wraps were also applied over the quadriceps muscle. They were heated to 74 deg C and applied through 5 layers of towels (Chattanooga Instruments, Chattanooga Tn).

3.11 Procedures

The purpose of these experiments was to measure temperature and blood flow in both skin and muscle with the 3 over the counter modalities for pain relief: ThermaCare Heat Wraps, Icy Hot Patches, ThermaCare Moist heat wraps over a 2 hour period. Hydrocollator wraps (used clinically) were left on for only 15 minutes since this is the standard length of time, they are used in a clinical setting due to high heat. They are considered a moist heating modality since they are soaked in hot water. On each day, subjects entered a 22°C room and sat for 20 minutes to acclimatize. Skin covering the belly of the quadriceps was cleaned as described under" Methods", and temperature

and blood flow probes were placed into the muscle and on the skin. Probes were located 1 cm apart on the skin surface.

On any given day, following placement of thermocouples and probes, one of four products were placed or applied on the skin for 2 hours. Skin blood flow and temperature were measured at the beginning of the 2-hour period and at 30 minute intervals for its duration.

ThermaCare Heat, hydrocollator heat pads and Moist heat wraps, when used, were laid on the skin over the quadriceps so that the center of the rap was immediately over the 2 needle insertion points.

IcyHot Patches (10 x 20 cm), when used, were placed over the same area, and placed in strips which formed a surface area the size of the ThermaCare heat wrap but allowed a hole, 1cm diameter in the center to assure that Menthol from the wrap would not come in contact with the catheters or needle insertion points.

3.12 Data Analysis:

Statistical analysis involved the calculation of means and standard deviations and ANOVA and T tests. The level of significance was $p<0.05$.

4. Results

Figures 1-4 show the results for the study. Figure 1 represents the skin blood flow data on each of the 4 modalities and for the 2 hour period. The blood flow is in Flux units.

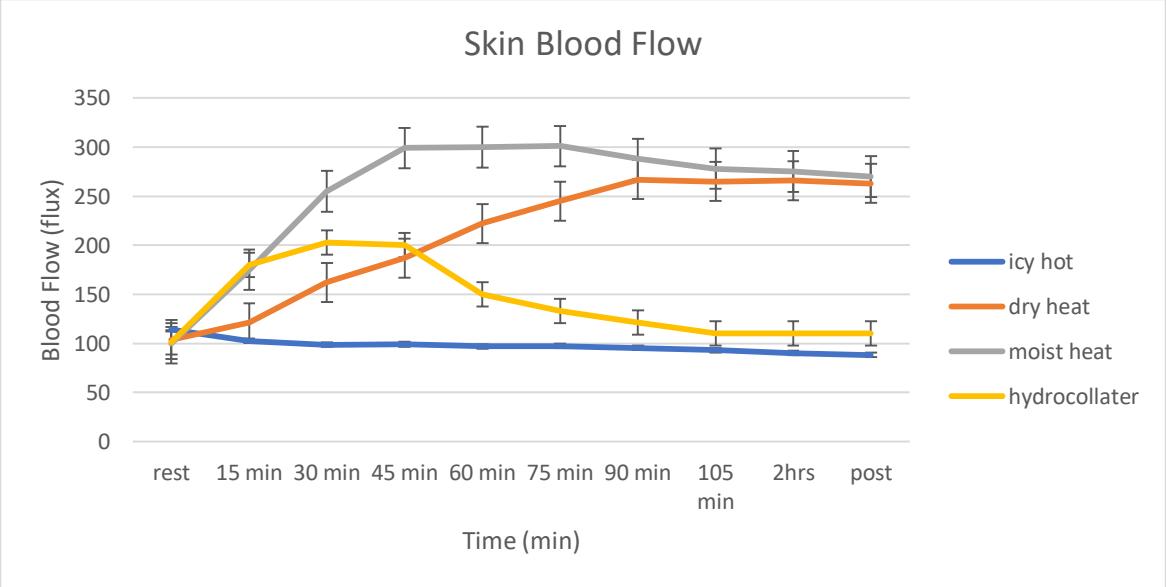

Figure 1- Illustrated here is the skin blood flow measured at 15-minute intervals for 2 hours after application of each of the 4 modalities. Each point is the mean of 10 subjects +/- the SD for Icy hot, Dry chemical heat, Moist chemical heat and Hydrocollator heat wraps.

As shown in this Figure, the greatest increase in skin blood flow was with moist heat. Dry heat was second and icy hot was the least. For example, between 60 minutes and 2 hours, the blood flow for moist heat was significantly higher than the other modalities ($p<0.01$). Skin blood flow increased about 300% after the moist heat was applied after 45 minutes, low level continuous dry heat almost 300% but it took 105 minutes to reach this flow, hydrocollator heat wraps increased by about 200% but only for only first 45 minutes and then back to baseline, a slight reduction in skin blood flow was seen with Icy Hot gel applied to the skin.

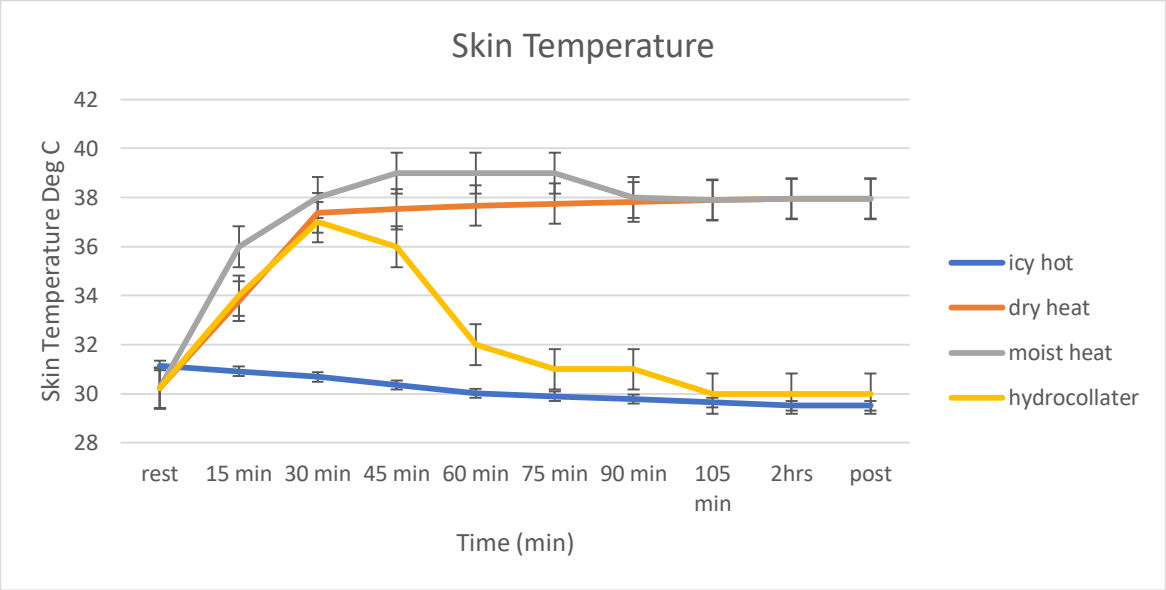

Figure 2- Illustrated here is the skin temperature measured at 15-minute intervals for 2 hours after application of each of the 4 modalities. Each point is the mean of 10 subjects +/- the SD for Icy hot, Dry chemical heat, Moist chemical heat and Hydrocollator heat wraps.

Skin temperature is shown in Figure 2 at rest and for 2 hours post modality application. Moist heat, hydrocollator and dry heat all increased skin temperature to near 38 Deg C in 45 minutes with moist heat significantly faster at 15 minutes($p<0.05$). With icy hot, skin temperature decreased over the 2 hour period while hydrocollator heat packs, only applied for 15 minutes, saw a 30 min peak in temperature followed by a decline.

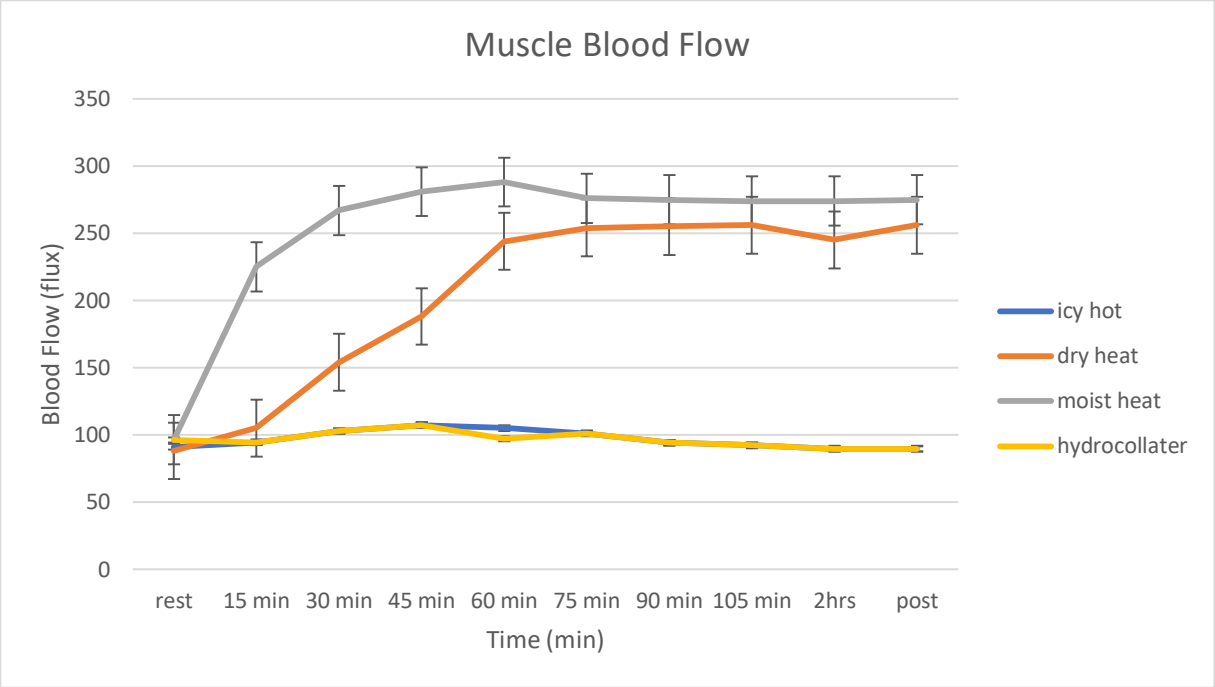

Figure 3- Illustrated here is the muscle blood flow measured at 15-minute intervals for 2 hours after application of each of the 4 modalities. Each point is the mean of 10 subjects +/- the SD for Icy hot, Dry chemical heat, Moist chemical heat and Hydrocollator heat wraps.

As shown in Figure 3, The increase in muscle blood flow was fastest after moist heat packs followed by low level continuous heat wraps (ThermaCare). The peak blood flow was in 45 minutes after moist heat and 1 hours with dry low level continuous heat. Icy hot and hydrocollator heat packs showed only a small increase in tissue blood flow. From 45 minutes to the end, muscle blood flow was significantly higher in the moist and dry heat groups than the other groups ($p<0.05$) and different from each other ($p<0.05$).

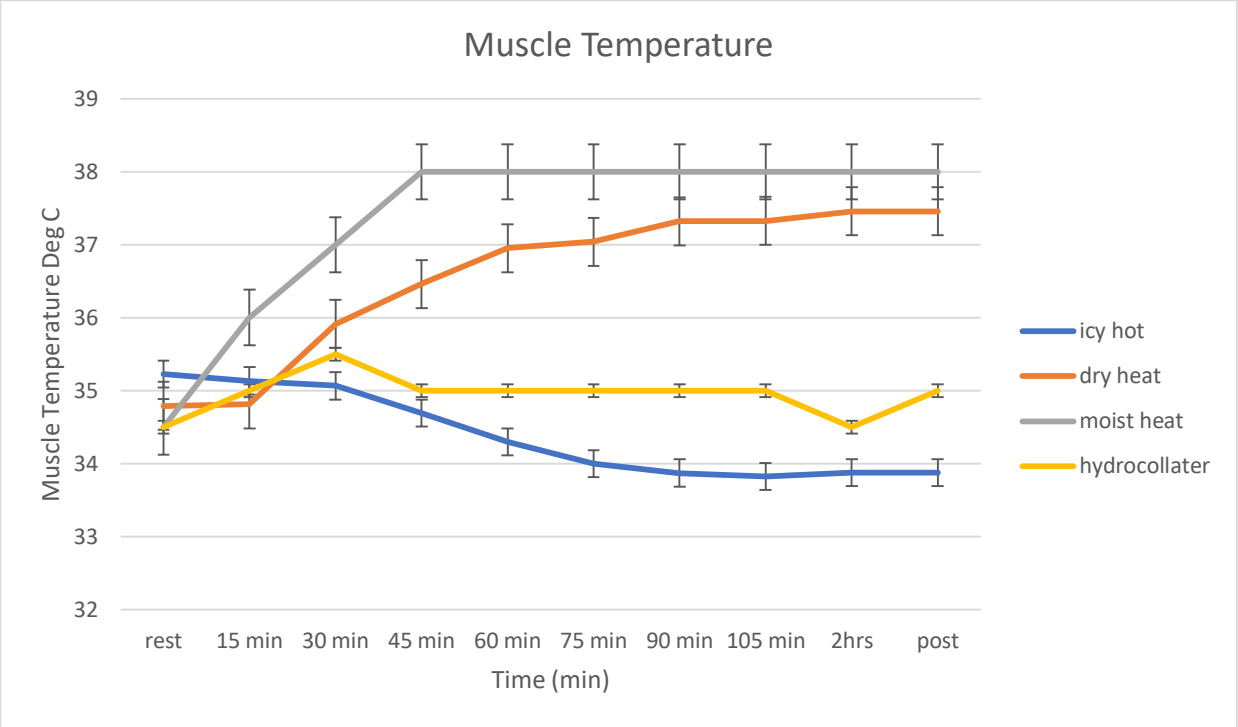

Figure 4- Illustrated here is the muscle temperature measured at 15-minute intervals for 2 hours after application of each of the 4 modalities. Each point is the mean of 10 subjects +/- the SD for Icy hot, Dry chemical heat, Moist chemical heat and Hydrocollator heat wraps.

Muscle temperature showed a similar response to skin temperature. Icy hot caused a decrease in muscle temperature. Moist heat caused muscle temperature to increase by an average of 3.1 Deg C. Dry heat caused muscle temperature to increase by 2.2 Deg C, while hydrocollator packs increased temperature by 0.4 degree C. Icy hot had no effect on muscle temperature.

5. Discussion

Numerous modalities are available to provide heat to the body to potentially reduce the symptoms of DOMS and promote healing. The concept is that heat will increase tissue blood flow and wash out biproducts of damaged tissue plus increase metabolism to promote healing. However, it is assumed that heat modalities will deliver heat to deep tissues and that heat will increase circulation and not just warm the skin.

In the present investigation, we examined 4 different heating modalities that are meant to produce deep tissue heating and increase tissue blood flow to reduce pain from muscle damage and DOMS. The normal deep tissue temperature in the limbs is usually far below that of core temperature (37 deg C)[38,39]. In contrast, skin temperature is usually around 31 ^{o}C and, muscle temperature falls short of the core when muscle is not actively exercising averaging perhaps 32 ^{o}C on most peripheral muscles[38,39]. This allows excess heat from the core to be lost down a thermal gradient from muscle to skin and then into the environment as described by the Pennes

equation[40]. If the skin is warmed, heat flows from skin into muscle and warms muscle. All 4 modalities that were examined here have been used to treat DOMS and with different results. ThermaCare heat wraps applied just after exercise reduce the duration and magnitude of Doms and apparent muscle damage because less strength is lost after exercise in the first 3 days[2]. Moist heat wraps (ThermaCare) showed similar results but provided greater pain relief and healing after heavy exercise[3]. Icy Hot also reports that the combination of menthol in the patch reduces pain [41]. Likewise, hydrocollator heat packs are used in clinical settings for pain[42]. Actual measures of deep muscle temperature and blood flow have been lacking to do a head-to-head comparison with these common modalities. The vasodilation results from 2 different mechanisms. Initially, heat prompts rapid vasodilation by promoting release of neurotransmitters (e.g., calcitonin gene-related peptide and substance P) from endothelial cells.[43,44] A second, independent, more gradual increase in blood flow resulting from heat may be mediated by activation of endothelial nitric oxide (NO) synthase, and production of NO to produce vasodilation.[44,45]

For ThermaCare Heat Wraps, skin warmed steadily over the 2 hour test period. Here skin warmed quickly followed by a rise in muscle temperature as might be predicted from the Pennes heat transfer equations[46]. As shown by Pennes, heat moves down its concentration gradient from the skin into muscle; the reverse of the normal pattern of heat loss from muscle to skin which normally allows for tissue cooling. Heat will increase tissue metabolism. For every 2 degrees increase in tissue temperature, metabolism doubles[47]. Therefore, tissue can heal faster. The increased circulation should also flush histamines from the muscle tissue and reduce pain due to heat activating TRPV-1 channels to inhibit skin and muscle pain[12,13]. It is not surprising then, that ThermaCare has been shown to be effective to reduce pain and allow for faster healing with muscle damage such as DOMS.

The increase in skin and muscle temperature was even faster with ThermaCare moist heat. Moist air carries more heat than dry air and increases conductive heat exchange[48]. These wraps therefore provide much faster heat transfer into deep tissue. This is expressed in this study as a faster increase in deep tissue blood flows. This would explain the greater pain relief and faster healing in people with DOMS using moist heat wraps[3].

In contrast, Icy Hot Patches contain only menthol. While there are numerous menthol receptors in the body, the TRPM 8 receptors seem to predominate in the response to menthol[49] causing a reduction in peripheral pain and a general feeling of cooling. But here, in addition to this general feeling of cooling, probably due to the evaporative loss of menthol on the skin and a direct effect of menthol in reducing circulation[50,51], there was a reduction in skin blood flow. As predicted by Pennes, this would cause skin temperature to fall. This occurred here. Over time, this caused muscle temperature to also fall due to greater heat transfer from muscle to skin. While it is good that there may be pain relief with Icy Hot menthol products, since cold reduces tissue

metabolism, Icy Hot may feel good but slow healing.

Hydrocollator heat packs are commonly used in therapy. The temperature is high and therefore, 5 layers of towels typically separate the heat pack from the skin. This limits heat transfer to the skin[31]. Since these packs do not hold heat for long periods of time, the modality is usually 15 minutes in duration. Therefore, the skin heats rapidly and blood flow in the skin also increases, but the increased heat gradient is too short to transfer heat into deep tissue. In these subjects examined here, there was little change in deep tissue temperature or blood flow.

But there are other factors not examined here. The thickness of the subcutaneous fat layer insulates muscle from changes in temperature[31]. Therefore, for people who are overweight, hydrocollator heat packs and icy hot would have very little effect on deep muscle. Even moist and dry heat would show a blunted response in transferring heat into muscle. These groups need to be examined with this and other heat modalities.

6. Conclusions.

Continuous moist heat provided the fastest rate of rise of skin temperature and blood flow and the greatest penetration of heat into muscle. For this reason, the increase in muscle blood flow was the greatest of the 4 modalities examined here. Continuous low-level heat (ThermaCare) was slower in heating the skin and muscle but still provided a good increase in deep muscle temperature and blood flow. Hydrocollator heat packs did not transfer heat well into muscle and was only on the leg for a short duration due to the high temperature of the pack. Finally, Icy Hot provided no heating and no increase in skin or muscle blood flow.

Acknowledgements:
None
Conflicts of interest:
none
Financial Disclosure:
None

Bibliography

1. Fitzgerald GK, Rothstein JM, Mayhew TP, Lamb RL. Exercise-induced muscle soreness after concentric and eccentric isokinetic contractions. *Phys Ther.* 1991;71(7):505-513.
2. Petrofsky J, Berk L, Bains G, Khowailed IA, Lee H, Laymon M. The Efficacy of Sustained Heat Treatment on Delayed-Onset Muscle Soreness. *Clin J Sport Med.* 2017;27(4):329-337.
3. Petrofsky J, Berk L, Bains G, et al. Moist heat or dry heat for delayed onset muscle soreness. *Journal of clinical medicine research.* 2013;5(6):416-425.
4. Al-Nakhli HH, Petrofsky JS, Laymon MS, Berk LS. The use of thermal infra-red imaging to detect delayed onset muscle soreness. *Journal of visualized experiments : JoVE.* 2012(59).
5. Cleary MA, Sitler MR, Kendrick ZV. Dehydration and symptoms of delayed-onset muscle soreness in normothermic men. *J Athl Train.* 2006;41(1):36-45.
6. Hotfiel T, Freiwald J, Hoppe MW, et al. Advances in Delayed-Onset Muscle Soreness (DOMS): Part I: Pathogenesis and Diagnostics. *Sportverletzung Sportschaden : Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin.* 2018;32(4):243-250.
7. Heiss R, Lutter C, Freiwald J, et al. Advances in Delayed-Onset Muscle Soreness (DOMS) - Part II: Treatment and Prevention. *Sportverletzung Sportschaden : Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin.* 2019;33(1):21-29.
8. Abraham WM. Factors in delayed muscle soreness. *Medicine and science in sports.* 1977;9(1):11-20.
9. Newham DJ, McPhail G, Mills KR, Edwards RH. Ultrastructural changes after concentric and eccentric contractions of human muscle. *J Neurol Sci.* 1983;61(1):109-122.
10. Newham DJ, Mills KR, Quigley BM, Edwards RH. Pain and fatigue after concentric and eccentric muscle contractions. *Clin Sci (Lond).* 1983;64(1):55-62.
11. Smith LL. Acute inflammation: the underlying mechanism in delayed onset muscle soreness? *Med Sci Sports Exerc.* 1991;23(5):542-551.
12. Farzin D, Asghari L, Nowrouzi M. Rodent antinociception following acute treatment with different histamine receptor agonists and antagonists. *Pharmacol Biochem Behav.* 2002;72(3):751-760.
13. Mobarakeh JI, Sakurada S, Katsuyama S, et al. Role of histamine H(1) receptor in pain perception: a study of the receptor gene knockout mice. *Eur J Pharmacol.* 2000;391(1-2):81-89.
14. O'Connor PJ, Cook DB. Exercise and pain: the neurobiology, measurement, and laboratory study of pain in relation to exercise in humans. *Exerc Sport Sci Rev.* 1999;27:119-166.
15. Al-Nakhli HH, Petrofsky JS, Laymon MS, Arai D, Holland K, Berk LS. The use of thermal infrared imaging to assess the efficacy of a therapeutic exercise program in individuals with

diabetes. *Diabetes Technol Ther.* 2012;14(2):159-167.

16. Bloomer RJ. The role of nutritional supplements in the prevention and treatment of resistance exercise-induced skeletal muscle injury. *Sports Med.* 2007;37(6):519-532.
17. Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness : treatment strategies and performance factors. *Sports Med.* 2003;33(2):145-164.
18. Mayer JM, Mooney V, Matheson LN, et al. Continuous low-level heat wrap therapy for the prevention and early phase treatment of delayed-onset muscle soreness of the low back: a randomized controlled trial. *Arch Phys Med Rehabil.* 2006;87(10):1310-1317.
19. Aminian-Far A, Hadian MR, Olyaei G, Talebian S, Bakhtiary AH. Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. *J Athl Train.* 2011;46(1):43-49.
20. Howatson G, Goodall S, van Someren KA. The influence of cold water immersions on adaptation following a single bout of damaging exercise. *Eur J Appl Physiol.* 2009;105(4):615-621.
21. Hirose L, Nosaka K, Newton M, et al. Changes in inflammatory mediators following eccentric exercise of the elbow flexors. *Exerc Immunol Rev.* 2004;10:75-90.
22. Thompson HS, Maynard EB, Morales ER, Scordilis SP. Exercise-induced HSP27, HSP70 and MAPK responses in human skeletal muscle. *Acta Physiol Scand.* 2003;178(1):61-72.
23. Petrofsky J, Batt J, Bollinger JN, Jensen MC, Maru EH, Al-Nakhli HH. Comparison of different heat modalities for treating delayed-onset muscle soreness in people with diabetes. *Diabetes Technol Ther.* 2011;13(6):645-655.
24. Petrofsky JS. The effect of type-2-diabetes-related vascular endothelial dysfunction on skin physiology and activities of daily living. *J Diabetes Sci Technol.* 2011;5(3):657-667.
25. Petrofsky J, Paluso D, Anderson D, et al. The ability of different areas of the skin to absorb heat from a locally applied heat source: the impact of diabetes. *Diabetes Technol Ther.* 2011;13(3):365-372.
26. Rabini A, Piazzini DB, Tancredi G, et al. Deep heating therapy via microwave diathermy relieves pain and improves physical function in patients with knee osteoarthritis: a double-blind randomized clinical trial. *European journal of physical and rehabilitation medicine.* 2012;48(4):549-559.
27. Rabini A, Piazzini DB, Bertolini C, et al. Effects of local microwave diathermy on shoulder pain and function in patients with rotator cuff tendinopathy in comparison to subacromial corticosteroid injections: a single-blind randomized trial. *J Orthop Sports Phys Ther.* 2012;42(4):363-370.
28. Guild DG. Mechanical therapy for low back pain. *Prim Care.* 2012;39(3):511-516.
29. Petrofsky JS, Laymon M. Heat transfer to deep tissue: the effect of body fat and

heating modality. *J Med Eng Technol.* 2009;33(5):337-348.

30. Petrofsky J, Berk L, Alshammari F, et al. The effect of moist air on skin blood flow and temperature in subjects with and without diabetes. *Diabetes Technol Ther.* 2012;14(2):105-116.
31. Petrofsky J, Bains G, Prowse M, et al. Dry heat, moist heat and body fat: are heating modalities really effective in people who are overweight? *J Med Eng Technol.* 2009;33(5):361-369.
32. Petrofsky J, Lohman E, 3rd, Lee S, et al. Effects of contrast baths on skin blood flow on the dorsal and plantar foot in people with type 2 diabetes and age-matched controls. *Physiother Theory Pract.* 2007;23(4):189-197.
33. Petrofsky JS. A device to measure heat flow through the skin in people with diabetes. *Diabetes Technol Ther.* 2010;12(9):737-743.
34. Petrofsky JS, Laymon MS, Alshammari FS, Lee H. Use of Low Level of Continuous Heat as an Adjunct to Physical Therapy Improves Knee Pain Recovery and the Compliance for Home Exercise in Patients With Chronic Knee Pain: A Randomized Controlled Trial. *J Strength Cond Res.* 2016;30(11):3107-3115.
35. Petrofsky JS, Lohman E, 3rd, Suh HJ, et al. The effect of aging on conductive heat exchange in the skin at two environmental temperatures. *Med Sci Monit.* 2006;12(10):CR400-408.
36. Petrofsky J, Bains G, Prowse M, et al. Does skin moisture influence the blood flow response to local heat? A re-evaluation of the Pennes model. *J Med Eng Technol.* 2009;33(7):532-537.
37. Petrofsky JS, Laymon M, Berk L, Bains G. Effect of ThermaCare HeatWraps and Icy Hot Cream/Patches on Skin and Quadriceps Muscle Temperature and Blood Flow. *J Chiropr Med.* 2016;15(1):9-18.
38. Petrofsky JS, Lind AR. Insulative power of body fat on deep muscle temperatures and isometric endurance. *J Appl Physiol.* 1975;39(4):639-642.
39. Petrofsky JS, Lind AR. The relationship of body fat content to deep muscle temperature and isometric endurance in man. *Clin Sci Mol Med.* 1975;48(5):405-412.
40. Pennes HH. Analysis of tissue and arterial blood temperatures in the resting human forearm. 1948. *J Appl Physiol.* 1998;85(1):5-34.
41. Castro E, Dent D. A comparison of transdermal over-the-counter lidocaine 3.6% menthol 1.25%, Rx lidocaine 5% and placebo for back pain and arthritis. *Pain Manag.* 2017;7(6):489-498.
42. Cordray YM, Krusen EM, Jr. Use of hydrocollator packs in the treatment of neck and shoulder pains. *Arch Phys Med Rehabil.* 1959;40(3):105-108.
43. Magerl W, Treede RD. Heat-evoked vasodilatation in human hairy skin: axon reflexes due to low-level activity of nociceptive afferents. *J Physiol.* 1996;497 (Pt 3):837-848.
44. Minson CT, Berry LT, Joyner MJ. Nitric oxide and neurally mediated regulation of skin blood flow during local heating. *J Appl Physiol (1985).* 2001;91(4):1619-1626.

45. Kellogg DL, Jr., Liu Y, Kosiba IF, O'Donnell D. Role of nitric oxide in the vascular effects of local warming of the skin in humans. *J Appl Physiol (1985).* 1999;86(4):1185-1190.
46. Pennes HH. Analysis of tissue and arterial blood temperatures in the resting human forearm. *J Appl Physiol.* 1948;1(2):93-122.
47. Edwards RH, Harris RC, Hultman E, Kaijser L, Koh D, Nordesjo LO. Effect of temperature on muscle energy metabolism and endurance during successive isometric contractions, sustained to fatigue, of the quadriceps muscle in man. *J Physiol.* 1972;220(2):335-352.
48. Petrofsky JS, Bains G, Raju C, et al. The effect of the moisture content of a local heat source on the blood flow response of the skin. *Arch Dermatol Res.* 2009;301(8):581-585.
49. Hassan ES. Thermal therapy and delayed onset muscle soreness. *J Sports Med Phys Fitness.* 2011;51(2):249-254.
50. McKemy DD. How cold is it? TRPM8 and TRPA1 in the molecular logic of cold sensation. *Mol Pain.* 2005;1:16.
51. Johnson CD, Melanaphy D, Purse A, Stokesberry SA, Dickson P, Zholos AV. Transient receptor potential melastatin 8 channel involvement in the regulation of vascular tone. *Am J Physiol Heart Circ Physiol.* 2009;296(6):H1868-1877.

