EFFECTS OF TRANSDERMAL MAGNESIUM CHLORIDE ON RECOVERY OF FORCE
PRODUCTION AND PERCEIVED MUSCLE SORENESS AFTER ECCENTRIC EXERCISE

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ABSTRACT

Michael Henry Bass: Effects of Transdermal Magnesium Chloride on Recovery of Force
Production and Perceived Muscle Soreness after Eccentric Exercise
(Under the Direction of Erik Hanson)

Purpose: To examine the effects of transdermal magnesium chloride ($tMgCl_2$) application on recovery in isometric force production and perceived muscle soreness following a bout of eccentric leg extensions. **Methods:** 19 recreationally active men completed a randomized, double blinded, crossover of isometric force production and muscle soreness assessment. Isometric knee extensor strength and perceived muscle soreness were assessed immediately following eccentric exercise intervention and at 24, 48, and 96 hours. **Results:** $tMgCl_2$ did not reduce perceived muscle soreness (p=0.510) or increasing muscle force recover (p=0.742). However, there was a slightly attenuated degree of pain and 4% increase in force production after accounting for the effects of leg dominance. **Conclusion:** $tMgCl_2$ may be beneficial for the micro-cycle phase of training. Future studies should consider investigating using higher dosages or longer supplementation periods to determine if $tMgCl_2$ improves muscle force following eccentric exercise.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

ATP: Adenosine triphosphate

Ca^{2+}:   Calcium ions

CK: Creatine Kinase

DOMS: Delayed Onset Muscle Soreness

EIMD: Exercise Induced Muscle Damage

Mg: Magnesium

Mg^{2+}:   Magnesium ions

NMDA: N-methyl-D-aspartate

MB: Myoglobin

$MgCl_2$:   Magnesium Chloride

VAS: Visual Analogue Scale

CHAPTER I: Introduction

Athletic success is often decided by the slimmest of margins, with the slightest advantage in performance being the difference between victory and defeat. To maximize performance, athletes may elicit extraneous sources of aid, which can be in the form of supplementation. It is common for athletes to turn to supplementation and other ergogenic aids to help them reach their maximum potential during events (Knapik 2016). From 2013-2018, supplement sales in the U.S. have almost grown by 14 billion dollars and is projected to reach 52 billion dollars by the end of 2019 (Statista). There is a multitude of different vitamins, minerals, and other herbal products available that claim to boost baseline levels within the body or, to minimize or reverse potential deficiencies, and theoretically providing athletes with physiologically optimal conditions to perform and compete. Because supplements are unregulated and often lack scientific evidence to support such claims, data are necessary to support or refute purported benefits. While some nutritional supplements have evidence to support their effectiveness (Peeling et al., 2018), many products have nothing more than anecdotal evidence or manufacturer claims.

Magnesium is of the most commonly reported deficiencies (Moshfegh et al. 2009) yet is necessary for more than 300 enzymatic process (Jahnen-Dechent 2012), including ATP production

and muscle force production during in the contraction cycle (Newhouse et al, 2000, Bohl et al, 2002). Magnesium also plays a pivotal role in protein synthesis, proper muscle and nerve function, blood pressure and glucose maintenance (Institute of Medicine 1997, Rude RK 2010, Rude RK 2012). This mineral is also necessary for different metabolic processes and the subsequent energy production, including oxidative phosphorylation and glycolysis. Magnesium is also a key factor in developing bone, genetic coding, and the maintaining of structure and function of the cellular membrane (Rude RK 2012). Proper functioning is imperative to adequate force output necessary for many athletic competitions, especially in those that require sustained high levels of lower body power output. The ability to maintain force production during high intensity efforts may help prevent fatigue and improve athletic performance.

Serum magnesium levels and muscle performance have been shown to be positively correlated for outcomes like grip strength and vertical jump (Brilla et al 1992: Santos et al 2012). However, most studies examining the effects of magnesium on performance utilize oral magnesium supplementation or dietary intake (Zhang 2017). Oral magnesium supplementation has been shown to have a positive effect on magnesium levels within the body while enhancing some performance outcomes like grip strength, lower-leg muscle power, knee extension torque, and ankle extension strength (Dominguez 2006). However, this method of ingestion and absorption may not be the most effective. One of the caveats of oral intake is that the magnesium has to be absorbed through the intestinal track before moving into the blood stream (Sircus 2007). This method of entry also requires that the magnesium be carried throughout the blood stream to working muscles to be used at the cellular level. This is less than ideal during athletic performance.

The majority of dietary magnesium is absorbed through the small intestine, with approximately 24–76% is absorbed in the gut and the rest is eliminated in the feces (Jahnen-Dechent 2012). This less than optimal absorption may be accompanied by some of the more common side effects of oral supplementation like nausea and mild diarrhea (Venturini 2015). Transdermal application may provide a more optimal delivery for use in sport, by circumventing the digestion track and avoiding the gastrointestinal absorption.

Transdermal magnesium chloride ($tMgCl_2$) is an alternative application method that may reduce some of the limitations seen with oral intake. Transdermal application provides a more direct localized approach by applying the supplemental magnesium as a topical agent and allowing the magnesium ions to diffuse through the epidermis layer (Sircus 2007, Chandrasekaran et al 2016). As such, this application style directly targets the muscles after being absorbed through the epidermal layer without having to enter into circulation. There has been evidence of oral supplementation having a positive effect on performance, but the effectiveness of transdermal delivery showing the same result has yet to be shown, thus recommending this application method currently lacks support (Gröber 2017).

Currently the use of $tMgCl_2$ to aid muscle performance has not been thoroughly researched (Zhang 2017). There has only been one study, to our knowledge, investigating the utilization of $tMgCl_2$ on muscle performance (Gulick 2012). This study found no differences between $tMgCl_2$ and placebo for cycling time to failure, but there was a difference over time in measuring ankle flexibility. While Gulick and colleagues did not detect any effects from $tMgCl_2$, they used an acute

application protocol. The use of repeated $tMgCl_2$ over multiple time points (chronic supplementation) allows for a more direct comparisons to the use of oral supplementation. Moreover, with the anti-inflammatory properties of magnesium in regards to cellular maintenance, it is possible that $tMgCl_2$ may be suitable to examine during the on recovery process. With increased recovery from strenuous bouts of exercise, athletes may be able to train harder in terms of intensity and volume during the microcycle, thus allowing for greater adaptations during the macrocycle. These small adaptations throughout the training program may be the difference in victory and defeat.

Purpose Statement

- Purpose of this study was to examine the effects of $tMgCl_2$ application on recovery in isometric force production and perceived muscle soreness following a bout of lower body eccentric leg extensions.

Research Questions

RQ1: Does $tMgCl_2$ enhance recovery and subsequently increase isometric force production after a bout of eccentric leg extensions on an isokinetic dynamometer?

RQ2: Does $tMgCl_2$ decrease muscle soreness after a bout of eccentric leg extensions?

Hypotheses

1) There would be a significant interaction of time and condition, and applying $tMgCl_2$ oil and balm three times daily following eccentric leg extensions will increase rates of recovery of isometric force production at 24, 48, and 96 hours compared to a placebo.

2) There would be a significant interaction of time and condition, and application of $tMgCl_2$ oil and balm will decrease perceived muscle soreness following eccentric leg extensions compared to a placebo

Operational Definitions

- *Familiarization:* Session that occurred prior to the pre-testing session to introduce and prepare the participants to successfully complete the protocols and equipment being used in this study.

- *Isokinetic dynamometer:* A device that resisted applied forces and controlled the speed of exercise at a predetermined rate.

- *Isometric force production:* Muscular force measured from an isometric contraction

Delimitations

- All participants were males between the ages of 18 and 35 and were recreationally active (30 minutes of exercise at least 2 times per week) for at least 2 months prior to enrollment

- All participants had previous experience (at least 2 months) with resistance exercises

- Participants had no history of knee injuries with surgery in the past year

- Participants must not have previously had any known magnesium deficiency, magnesium supplementation therapy or multi-vitamin use

- Participants were not taking chronic pain medication

- All participants had no history of cardiovascular or respiratory conditions which could have been exacerbated by short duration moderate intensity exercise

Limitations

- The results of this study were only applicable to those who are men, recreationally active and between the ages of 18-35 years old. Results may not be applied to males of all ages and females

- It is possible that subjects did not adhere to supplement application or exercise guidelines during the trail weeks as researchers were not with them during the hours in-between testing sessions

- It was not feasible for our lab to measure magnesium levels delivered by application.

Assumptions

- All participants followed the pre-assessment guidelines.

- All participants followed supplement application protocol during the testing period.

- All participants refrained from all other forms of exercise during the testing period.

Significance of Study

Magnesium is essential to many of the enzymatic processes associated with exercise. However, the uses of $tMgCl_2$ as an aid to muscle performance have not been thoroughly researched. By examining the effects of a $tMgCl_2$ supplement on muscle soreness and force production compared to placebo, this study provided initial evidence to support a simple, affordable approach to reduce muscle damage following unaccustomed exercise. If proven effective this method of application could be used to further training efforts in the acute setting, by allowing athletes to recovery faster from intense training bouts and potentially allowing them

to accumulate greater training volumes and a greater cumulative effect in terms of chronic adaptations (Hartman 2015).

CHAPTER II: Literature Review

Eccentric Exercise and Exercise induced muscle damage (EIMD)

Eccentric Mechanisms of Muscle Damage

Exercise induced muscle damage (EIMD) can be categorized as the loss of muscle strength, and increase in muscle damage biomarkers and subsequent muscle soreness. (Nosaka et al., 1996, Byrne et al., 2004, Tee et al., 2007). Previous literature has suggested that failure of excitation-contraction and sarcomere over-extension is the factor driving eccentrically induced EIMD (Morgan et al., 1990, Warren et al., 2001, Raastad T, et al., 2010). Calcium overload is believed to also be an enabler of EIMD (Armstrong et al., 1991) Excess calcium within cells impedes cellular respiration in the mitochondria (Cullen et al,1979), thus slowing ATP production and inhibiting the ability of the tissue to discard calcium (Wrogemann and Penna 1976, Zulian et al., 2016). High calcium concentrations within the cell has been linked to structural and functional damaging of the mitochondria, cellular necrosis, z-disc degradation and energy shortage (Busch et al., 1972, Wrogemann and Penna 1976, Zulian et al., 2016).

An eccentric contractions consist of the active lengthening of muscle under an external load (Douglas et al, 2016). Eccentric exercise has been used to examine EIMD because it is believed contraction-induced muscle tissue damage is more likely to happen in exercises using muscle

lengthening during activation (Armstrong et al., 1991, Proske et al., 2001, Warren et al., 2001). Eccentric contractions has also been believed to create higher local temperatures than concentric contractions (Daves and Barnes 1972). A rise in localized muscle temperature from exercise can possibly increase EIMD by breaking down of muscle fibers and connective tissues (Armstrong, 1984) It has been shown that 3 sets of 30 maximal eccentric contractions of the knee extensors created a muscle damage response via significant increases in muscle damage biomarkers (Hody, 2013). The proposed study utilized a randomized crossover placebo design with 6 sets of 12 maximal eccentric contractions of knee extensors at 60° per/second utilizing a isokinetic dynamometer, which in theory would elicit a muscle damage response.

Force Production

Eccentric muscle contractions have been shown to cause greater fatigue and muscle soreness in comparison to isometric and concentric contractions (Jones et al., 1986). It has also been suggested that eccentric contractions cause the most soreness and damage at the tissue level (McCully and Faulkner, 1985). Microscopic evidence has shown muscle damage via myofibrillar disorganization and Z-line disruption due to eccentric exercise (Friden et al., 1981, Lewis et al., 2013). There is a temporary reduction in isometric force generating capacity due to the tissue damage from eccentric exercise (Bryne et al. 2004). 24-48 hours after EIMD, peak force production deficits tend to occur as a result of eccentric exercise (Smith, 1991). Isometric strength has been accepted as a valid and reliable means of assessing muscle function following eccentric exercise (Warren et.al 1999). Taking into consideration the data presented above, the present study measured the maximum voluntary isometric contraction ability of quadriceps at 0, 24, 48 and 96 hours after eccentric exercise and as an assessment of muscle function relative to baseline.

Delayed Onset Muscle Soreness (DOMS)

Delayed Onset Muscle Soreness (DOMS) is known as the development of pain, stiffness, and swelling of activated tissue from muscle micro trauma (Lewis et al., 2012) Previous literature has indicated that the swelling seen in DOMS is a result of EIMD and its consequent inflammatory response (Connolly et al., 2003). Input from mechanoreceptors may contribute to muscle soreness post eccentric exercise (Weekrakkoday et al 2001). It has been proposed that exercise-induced release of chemical substances that elicit pain such may be the mechanism causing DOMS (Fock and Mense 1976). These same chemicals are thought to innervate the pressure receptors of afferent nerve endings sending sensations of pain upon touch (Hiss and Mense, 1976). DOMs has been positively correlated with loss of force output and range of motion (Saxton et al., 1996, Prasarthwuth et al., 2006). Yet, there is evidence that DOMS has weak relationship with actual muscle damage (Rodenburg et al., 1993, Nosaka et al., 2002). DOMS appears to peak between 24 and 96 hours post exercise (Cheung et. Al, 2003). There has been work done with the visual analog scale (VAS) to effectively identify soreness in DOMS timelines (Lau et al., 2015, Kanda K et al., 2013). This proposed study evaluated muscle soreness using a VAS at 0, 24, 48 and 96 hours post eccentric exercise.

Magnesium's Role in Physiological Processes Relevant to Exercise
Mg^{2+} in Cellular metabolism

Magnesium at the cellular lever influences larger process such as membrane stabilization and metabolism of the muscle (Altura et al., 1996, Newhouse et al., 2000, Nielsen et al., 2006, Zhang 2017). In terms of metabolism, magnesium is pivotal to the allowance of enzymatic reactions. This function is critical to muscle recovery following exercise. Magnesium ions are also necessary for energy production within the cell. Processes such as glycolysis and beta oxidation rely on Magnesium enzymes (Swaminthan R, 2003, Pasternak et al, 2010).

Table 1 coveys the different enzymes, structures, and processes of energy metabolism that depend on Mg^{2+}.

Table 1: Physiological Functions of Magnesium (Swaminthan R, 2003)

Mg Dependent Processes	Mechanism Affected or Aided
Enzyme Function	Hexokinase Creatine Kinase Protein Kinase
Direct Enzyme Activation	Phosphofructokinase Creatine Kinase Adenylate Cyclase Na+, K+, ATPase
Membrane Function	Cell Lipid Adhesion Protein synthesis
Calcium antagonist	Muscular Contraction/Relaxation Neurotransmitter release Action Potential Conduction
Cell Structure and Function	Mitochondria Nucleic Acids

Adenosine triphosphate is viewed as the fuel for life and nearly every reaction utilizing ATP demands the presence of magnesium (Touyz, 2004).The Mg-ATP complex (figure 1) is pivotal in metabolism and energy production (Maguire, 2006). The Mg-ATP complex is essential in the catabolism of phosphotransferases, hydrolases, and ATPases during metabolic processes in the cell (Saris et al., 2000, Pasternak et al., 2010). While magnesium is well known to be essential to various metabolic and structural process, the specific nature of its role in tissue anabolism and catabolism is still uncertain. One of the more favored theories is that magnesium supports regeneration of tissue by aiding in cellular metabolism by assisting in the production of enzymes used for energy production (Lukaski et al., 2004, Nielsen, 2006).
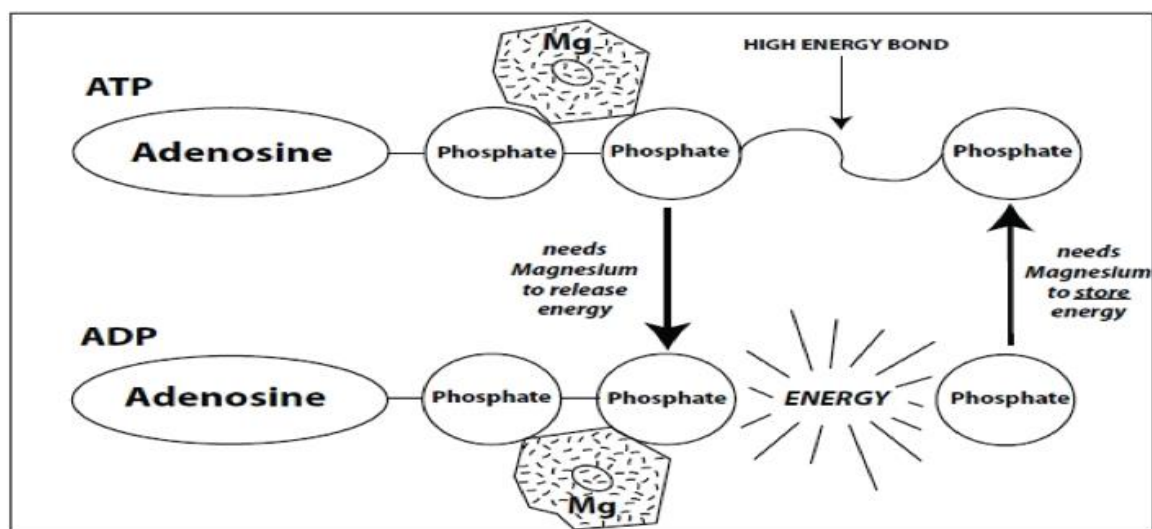
Figure 1: Magnesium is required for ATP to release stored energy to drive biological reactions within the cells (Rosanoff, 2015)

Collectively, these studies suggest that the effects of Mg^{2+} on cell lipid stabilization and protein synthesis are benefits to maintaining membrane integrity, which is often compromised during different forms of resistance exercise. There has been evidence that showcased that the electrical effects of magnesium ions provide a stabilizing effect (Bara et. Al, 1990) Magnesium ions in the cell has been theorized to help stabilize the cell with its inhibition of calcium ion uptake (Kowaltowski et al., 1998, Iseri et al., 1984). It has also been suggested that magnesium helps to boost membrane function by binding to cellular phospholipids and organelle membranes (Golf et Al, 1998). Cellular lipid stabilization and protein synthesis are usually inhibited during resistance exercise, thus effecting the membrane integrity. This aforementioned evidence points to magnesium being a key factor in alleviating this issue.

Magnesium's role in muscle contraction

During exercise, vasodilation of vessels allows for my oxygen to be delivered to work tissue by way. (Ishibashi et al., 1998, Duncker et al., 2008). This increased delivery of

oxygenated blood could allow for greater nutrient availability and repair post EIMD. There has

been a research showing that a rise in the presences of magnesium ions prior to exercise results

in increased blood flow allowing greater cross bridge formation (Haddy et. al, 1975). It has been

theorized that since magnesium functions as an counteractant to calcium channels via blocking

channels and decreasing intracellular calcium and consequent contractibility, which lowers

peripheral vascular resistance and lowering the chance of overloading of calcium (Altura et al.,

1987). This inhibition of calcium channels by magnesium ions may promote more efficient

contractions of working muscles by reducing the probability of calcium overload within the cell

(Swaminathan R, 2003). It is also believed that magnesium ions enable efficient muscular

contractions by allowing greater cross bride formation (Carvil P, Cronin J, 2010). All of these

possible enhancements of muscular contraction has yet to be examined through the scope of local

application of transdermal magnesium.

Magnesium's role in pain response

Magnesium is voltage dependent blocker of N-methyl-D-aspartate (NMDA) receptor

channels (Iseri and French, 1984, Ken and Kemp, 2005). NMDA receptor activation causes the

spinal neurons to be more sensitive to inputs, causing a heightened pain stimulus through central

sensitization (Bennett, 2000). There has been evidence that magnesium ions reduce

inflammatory pain by minimizing NMDA receptor activity (Petrenko et al., 2003, Nechifor,

2011). Post EIMD, there has been evidence that the muscle soreness experienced may be

associated with the release of inflammatory mediators (Moyer and Wagner, 2011, Kanda et al.,

2013). Magnesium ions have been shown to minimize the release of these mediators and

subsequently reducing the inflammatory response and consequent pain (Nechifor, 2011).

To our knowledge there has been no clinically controlled trials date investigating the effects of magnesium supplementation and DOMS from EIMD. However, there is a number of studies examining decreases in pain in clinical populations with oral supplementation. There has been evidence that oral supplementation of magnesium citrate in patients with coronary artery disease reduces exercise induced chest pain (Schester et al 2003). There has also been evidence that 1 month of daily oral magnesium oxide supplementation (300 mg) decreased chronic low back pain with a neuropathic component (Yousef and Al-deeb, 2013). In terms of magnesium chloride, there has been evidence that transdermal application minimized chronic pain in patients with fibromyalgia (Engen et al., 2015).

Magnesium supplementation/concentration's influence on performance

There has been conflicting evidence on the effects of oral magnesium supplementation and exercise performance (Zhang 2017). It has been shown that there is a positive association with dietary magnesium intake and maximal isokinetic knee extension and flexion torque in "elite" level basketball and handball players (Santos et al. 2011) (See figure 2 & 3). In professional male volleyball players there was similar research done with 1 month of magnesium oxide oral supplementation, 350mg/day, and an increase in peak counter movement jump height. However there was no significant difference in maximum force production of the knee extensors (Setaro et. al 2014).
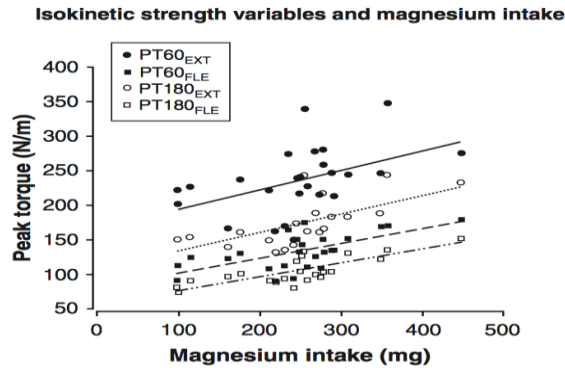
Figure 2: Dietary Magnesium Intake Correlation w/ Isokinetic Strength (Santos et al. 2011).
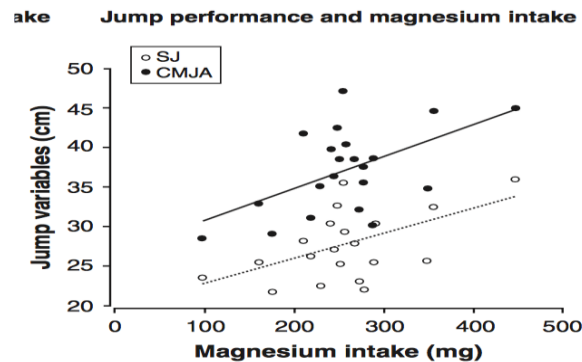
Figure 3: Dietary Magnesium Intake Correlation with Jump Performance (Santos et al. 2011)

The benefits of magnesium supplementation has also been seen in non-athletic populations. In untrained individuals, oral supplementation of magnesium oxide (8mg/kg) increased quadriceps torque in comparison to the placebo group (Brilla et al., 1992). The InCHIANTI study examined the effects of magnesium on muscle performance in an elderly population. This examination showcased a positive correlation between serum magnesium levels and maximal handgrip strength and knee extension torque (Dominguez et al., 2006). It is imperative to note that the InCHIANTI study did not utilize supplementation. However, this data does suggest that higher circulating levels of magnesium ions may be linked to having greater force production. The aforementioned research suggest that magnesium's role in metabolism and structure at the cellular level may impact muscular contraction and subsequent force production.

Transdermal MgCl₂ Treatment

For years there have been anecdotal evidence for the use of mineral based theories, majority of which pointing to the potential health benefits. There has been conflicting evidence on the effectiveness of magnesium ion penetration via transdermal application. One study found

that transdermal magnesium chloride supplementation penetrated the skin rapidly, and achieved significant permeation in 15 minutes (Chandrakanth et al 2016). However, there was no mention of the amount of magnesium that was able absorbed (Gröber 2017). After magnesium ions have crossed the stratum corneum, transmembrane proteins assist the transport of ions into the organ systems (Sahni et al. 2007). One study showcased that transdermal magnesium had greater effects than topical magnesium sulfate, which commonly used to treat pain (Bara et al., 1994). Transdermal magnesium chloride has also been favored in comparison to other topical agents, such as magnesium sulfate, because of its lower tissue toxicity (Durlach et al, 2005).

To our knowledge, there had only been one study to date that examines the positive anti-inflammatory effect of transdermal magnesium chloride supplementation in recreationally active individuals. In this study there was no correlation between the use of MagPro™ (Magnesium cream) and muscle flexibility or muscle endurance (Gulick et al 2012). We believed that due to the physiological processes that magnesium is involved in regards to contractibility and anti-inflammation, it was best to examine the effects of transdermal magnesium on strength recovery and pain measures. It has been hypothesized that transdermal magnesium is absorbed quickly and thus more readily available for cellular use that oral supplementation. This in turn improving the ability of the muscle to function and recover from intense muscular contraction (Circus 2007). A greater understanding of transdermal magnesium chloride was needed to justify claims and advertisements that it serves as an aid to muscle recovery following exercise.

CHAPTER III: Methodology

Participants

20 male subjects between the ages of 18-35 were recruited from a university in the southeast region of the United States. Due to the scarcity of previous literature regarding this particular application method in the desired population (Gulick et al, 2012), a sample size of 20 was collected. In order to be included in this study, participants had to be recreationally active, 30 or more minutes of exercise at least twice per week for a minimum of 2 months prior to enrollment. Each participant must also have had a previous history, within the past 3 months prior to enrollment, of resistance exercise. Each participant had to be free of any contraindications to exercise, acute knee injuries within the previous year, known magnesium deficiency, or utilizing magnesium supplementation and/or chronic pain medication in order to be enrolled. Females were excluded from this study due to there is a high degree of performance variability within women that appears to occur due to the menstrual cycle (Tenan et al 2015). To minimize those confounding factors and potential variation in muscle soreness and isometric force production, this initial pilot study was performed in males only.

Design

This study used a double blind, repeated measures crossover design. Participants were advised to abstain from any exercise or alcohol consumption 24-hours prior to arriving to the Exercise Oncology Lab for testing. Also, participants were instructed to not use an over the counter analgesics throughout the duration of the study.

Testing Methods

All testing and evaluations were performed in the Department of Exercise and Sport Science at the University of North Carolina in the Neuromuscular, Sports Medicine, and Exercise Oncology Laboratories located in Fetzer Hall.

Body Composition Assessment

Dual-energy X-Ray absorptiometry (DEXA; Hologic Discovery DXA System QDR Series, Hologic Breast and Skeletal Health Solutions, Marlborough, MA, USA) was used to estimate lean mass (LM), fat mass (FM), and bone mineral content to calculate total body composition. All scans were performed by a trained DEXA technician. Before each scan, the trained technician entered the required subject information including height (in), weight (lbs.), ethnicity, age, sex, and identification code. The participant was instructed to remove all metal jewelry and any other objects from their pockets, and then lie supine on the DEXA scanner. Once on the DEXA table, the technician adjusted the participant's head, hips, shoulders, and limbs to center the participant within the DEXA's measurement area. The participant was instructed to keep their hands pronated on the DEXA table next to their legs. The technician then inspected the positioning of the participant before wrapping the ankles to ensure the position was held throughout the scan. The participant was instructed to remain still in fixed position and maintain normal breathing the entire scan. Dependent on body size, the scan lasted between 7-13 minutes.

Blood Draw

All blood draws occurred in the Exercise Oncology Laboratory and was conducted by an individual trained in phlebotomy. ~10mL of blood was obtained. 4mL of blood was collected in an EDTA tube and complete blood counts with differential were determined in duplicate (XP-300 Automated Hematology Analyzer, Sysmex America Incorporated, Lincolnshire, Illinois, USA), along with hemoglobin and hematocrit for determination of plasma volume shifts (Dill and Costill, 1973). A 6mL serum sample was allowed to clot for 30 minutes at room temperature, then centrifuged (1200 rpm X 10 min. at room temperature) and serum was obtained and aliquoted. These serum samples were stored at -80°C in a freezer (Thermo Scientific XBF40D-MD-Blast Freezer for Plasma, Waltham, MA, USA).

Application of Condition- Placebo vs. Supplement

Technicians used an analytic balance (Fisher Scientific XA Analytic Balance, Fisher Scientific, Hampton, New Hampshire, USA) to measure the mass (g) of both the balm and oil of the specified condition, and recorded this on the data sheet. Technicians then provided the condition to the participants post final isometric strength test on visit 2 and 6. Participants was instructed to apply their condition (placebo or supplement) by spraying 5 sprays from their bottle onto their quadriceps muscle of the tested leg. Once the participant felt that the spray had dried on their leg, they applied a quarter size dollop of the balm given to their quadriceps muscle on the tested leg. The participants were instructed to apply their condition after each visit to the lab, and during the evening and morning throughout the entire duration weeks of testing. After visit 5 and visit 9, participants returned their balm and oil to the technician. The technician again used a

balance to measure the remaining mass of both the balm and oil of the specified condition, and recorded this on the data sheet.

Gravity Correction

Participants remained buckled in the dynamometer while the technician began the program "Research Toolkit". The technician ensured the participant was comfortable before running the program. Once the participant was comfortable, the technician used the dynamometer to bring the participant's knee to ~90 degrees flexion. A level was used to ensure that lower limb was vertical. The technician started the recording on the biopac (Biopac MP150, BIOPAC Systems Incorporated, Goleta, California, USA) and allowed the recording to run for 5 seconds. The participant was then unbuckled from the dynamometer.

Muscle Soreness: Visual Analogue Scale (VAS)

A 100cm line in which participants indicated the level perceived of soreness between 0 – 10. Each mark made on the analog line was examined to determine perceived muscle soreness for both the experimental and control supplements.

Cycle Ergometer Warm-up

Participants pedaled at light (25-50 watts) resistance for five minutes on the cycle ergometer prior to completing any exercise testing.

Isometric Muscle Strength

Participants were fitted to the isometric dynamometer (HUMAC Norm Testing and Rehabilitation System, Computer Sports Medicine Incorporated, Stoughton, MA, USA) and asked to perform single leg extension contractions at 50%, 75% and 90% of their perceived maximal effort with a knee angle of 90 degrees of flexion. Participants were given 1 minute to rest in between each warm-up effort. Participants then performed three, maximal isometric leg

extension efforts lasting 2-3 seconds, with 2 minutes of rest between each effort. The peak force from each trial was determined from the dynamometer and the highest value was used for calculations.

Eccentric Muscle Damage Protocol

To test the effects of the $tMgCl_2$ on muscle recovery, it was decided to use an eccentric leg extensions. Eccentric training, as a model of unaccustomed exercise, has been shown to decrease force output and increase soreness. (Cheung et al 2003, Newham et al 1986: Proske et al 2001). Participants remained seated in the isometric dynamometer for 3 minutes after the isometric strength testing and prior to the eccentric protocol. Participants then performed 6 sets of 12 consecutive unilateral eccentric isokinetic knee extension contractions at a speed of 60 degrees per second. Participants were asked to resist the downward movement of the dynamometer for all repetitions for a full range of motion, from ~0 degrees flexion through to 90 degrees of flexion.

Visit One

Participants were screened for participation in the study, which included a medical history questionnaire. If all inclusion criteria were met, participants were asked to sign the informed consent. Participants underwent a dual-energy x-ray absorptiometry scan to determine body and bone mineral composition. Then participants were taken to the neuromuscular lab to have the opportunity to practice and become familiar with all study procedures including knee extension strength testing, and eccentric leg extension protocol under submaximal conditions. As participants left the familiarization session, participants were reminded of the pre-exercise guidelines required for future visits.

Visit Two

      Participants returned to the testing site 3-7 days after the familiarization session. Before performing exercise testing, participants filled out the baseline muscle soreness VAS and the research performed a blood draw. Following this, participants completed the cycle ergometer warm up. Participants were then fitted into the dynamometer before beginning the isometric strength testing portion of the visit. Post isometric strength testing and 3 minute rest period, participants completed the eccentric muscle damage protocol. Following this, participants were given another muscle soreness VAS, before completing another isometric strength test bout. Upon completion of the final strength test, participants were fitted for the gravity correction. After the gravity correction, participants were taken back to the Oncology Lab where they had another blood draw and were given their condition. Researchers showed the participant how to apply to the quadriceps. After application, they were reminded of both the application times before the next visit and the pre-assessment guidelines.

Visit Three, Four, and Five

      Participants were asked to return to the lab for follow up muscle strength and soreness testing at 24h, 48h, and 96h after the eccentric exercise bout. Upon arrival to the lab, participants had their blood drawn and given a muscle soreness VAS. Participants were then taken to neuromuscular lab. In the lab they completed the cycle ergometer warm up before being fitted into the dynamometer for strength testing. Once fitted, the participants completed 1 bout of the isometric strength testing protocol before completing a gravity correction. After the gravity correction, the participant was unbuckled from the dynamometer and instructed to apply both their balm and oil to the tested leg. Before leaving, they were reminded of both the application times before the next visit and the pre-assessment guidelines. After the final strength testing

session (96 hr), participants were asked to return all supplements, to the researchers to estimate the amount of magnesium you received during the treatments.

Washout period:

2 weeks. During the washout period, participants were allowed and encouraged to resume their normal exercise routines. After the two-week washout period, participants returned to the laboratory and repeated the testing procedures using their opposite leg and the supplement condition.

Visits 6-9

Participants repeated testing (visits 2-5) from week 1 using the opposite supplementation condition. Participants used the opposite leg from week one to avoid a training or supplement effect from the first week of testing.

Timing

All participants were tested within ±1 hour of visit 2 for week 1 and visit 6 for week 2, as a means of controlling for variability in performance throughout the day.

Sample Size

To our knowledge, only one other study had investigated transdermal magnesium on muscle performance (Gulick et al, 2012) and the authors reported that in 18 healthy men and women, there was no effect on muscle endurance performance. Oral magnesium supplementation has been reported to enhance strength and Gulick and colleagues (2012) suggest that strength testing and also repeated applications of the product may produce larger effects. However, in the absence of scientific evidence to support this hypothesis, data by which to base statistical power calculations to estimate sample size are not available. As such, we are

approached this initial study as a pilot project in which we intended to improve upon existing

knowledge by examining a different role for transdermal magnesium supplementation in a

longitudinal manner, while restricting this initial study to males only. This initial project allowed

for more appropriate power analyses to be conducted based on effect sixes calculated for this

specific product in a more controlled population across a longer application period.

Statistical Analysis

Data will be analyzed using mixed-effects linear modeling (Jamovi 0.9.6.9) with repeated

measures for the 2x5 crossover design. Magnesport and placebo condition effects was analyzed

over time against perceived muscle soreness and maximal isometric force production. Potential

covariates, such as leg dominance, were explored using descriptive statistics and the presence of

an association with the dependent variables prior to being included in any statistical models. The

potential order effect of the dominant vs. non-dominant leg were tested by comparing time x leg

interaction of the dependent variable across time. The dominant leg was defined as the leg a

participant would use to kick a ball for maximal distance. All statistical analyses were performed

using Jamovi 0.9.6.9.

CHAPTER IV: Results

Participants

Participants were young, healthy, and recreationally active males with no history of lower extremity injuries within a year previous to testing (Table 1). All participants had at least two months of prior experience with resistance training. All participants considered themselves to be at least moderately active and partook in various modes of both aerobic and resistance exercise. Of the 20 participants that were recruited, one was lost to follow up due to a mild allergic reaction to compounds within the product.

Table 1. Participant characteristics (n=19).

	Mean ± SD	Range
Age (y)	22 ± 2	19-24
Height (cm)	177.4 ± 6.4	168.1-193
Mass (kg)	83.7 ± 12.5	66.6-107
Activity Levels (d/wk. ≥ moderate intensity)	4 ± 1	3-5
Fat Mass (kg)	17.3 ± 7.1	8.5-28.5
Lean Mass (kg)	64.0 ± 8.3	51.4-77.1
% Body Fat	20.4 ± 5.9	11.9-35.1

Whole Blood Markers and Hydration Status

There was no difference in white blood cell, hemoglobin, or hematocrit throughout the duration of the trial, nor any difference between conditions. Thus indicating that participants had similar hydration levels during testing and appeared to be free of illness (Table 2).

Table 2. Whole Blood Markers (n=14)

WBC (x10³/uL)	**Baseline**	**0H**	**24H**	**48H**	**96H**
tMgCl$_2$	7.1 ± 1.9	6.8 ± 1.4	6.1 ± 1.4	6.3 ± 1.1	6.6 ± 1.7
Placebo	6.4 ± 0.7	6.7 ± 1.4	6.3 ± 0.7	6.1 ± 1.0	6.8 ± 0.8
LYM (x10³/uL)					
tMgCl$_2$	2.2 ± 0.5	2.0 ± 0.5	2.3 ± 0.6	2.3 ± 0.4	2.2 ± 0.6
Placebo	2.1 ± 0.4	2.1 ± 0.6	2.3 ± 0.5	2.0 ± 0.5	2.1 ± 0.5
MXD (x10³/uL)					
tMgCl$_2$	0.8 ± 0.2	0.7 ± 0.3	0.5 ± 0.2	0.6 ± 0.3	0.7 ± 0.3
Placebo	0.6 ± 0.1	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.5 ± 0.1
NEUT (x10³/uL)					
tMgCl$_2$	4.1 ± 1.8	4.1 ± 1.4	3.3 ± 1.0	3.5 ± 1.0	3.7 ± 1.4
Placebo	3.7 ± 0.6	3.9 ± 1.1	3.3 ± 0.7	3.5 ± 0.9	4.2 ± 1.2
HGB (g/dL)					
tMgCl$_2$	14.8 ± 0.7	14.8 ± 0.7	15 ± 1.2	14.8 ± 1.0	15.0 ± 0.7
Placebo	14.9 ± 0.5	15.3 ± 2.0	14.8 ± 1.1	14.5 ± 1.0	14.7 ± 0.5
HCT (%)					
tMgCl$_2$	43.3 ± 2.0	43.2 ± 2.4	43.6 ± 2.3	43.1 ± 2.3	43.3 ± 2.1
Placebo	43.3 ± 1.5	44.9 ± 6.0	43.1 ± 2.4	42.4 ± 2.1	43.0 ± 1.3
PV (%)					
tMgCl$_2$		0.5 ± 5.9	-1.7 ± 8.9	1.9 ± 12.5	-1.6 ± 10.1
Placebo		7.8 ± 19.8	-4.4 ± 13.0	0.2 ± 6.8	2.9 ± 5.8

Mean ± SD

* p<0.05 compared to baseline; ** p<0.01 compared to baseline

tMgCl₂ Application

Participants appeared to be compliant with application guidelines for both conditions and there were no difference in the amount of product application between tMgCl$_2$ and placebo (Table 3). The amount of MgCl$_2$ delivered via transdermal oil was 743.7 ± 158.0 mg and 447.0 ± 352.0 mg via transdermal balm for a total of 1,190.7 ± 510 mg, which was an average of 99.2 ± 42.5 mg per application.

Table 3. Total Application Quantity for tMgCl₂ Oil and Balm (n=19).

	tMgCl$_2$	Placebo	P-Value
tMgCl$_2$ Oil (g)	8.0 ± 1.7	8.4± 2.6	0.805
tMgCl$_2$ Balm (g)	10.8 ± 8.5	11.2 ± 7.1	0.700
Mean ± SD			

Isometric Knee Extensor Muscle Strength

Immediately following eccentric exercise muscle contractions (0H), knee extensor isometric raw torque decreased by ~12% (-36.5 N*m, 95%CI [-6.3, 39.3], p<0.001) relative to baseline (Table 4). Torque tended to be lower than baseline at 24H (-10%, -15.9 N*m, 95%CI [-31.9, 0.2], p=0.055), was similar to baseline at 48H (1.3 N*m, 95%CI [-14.8, 17.4], p=0.877) before increasing by 16% at 96H (34.98 N*m, 95%CI [18.6, 51.3], p<0.001). There was no group x time interaction or condition main effect.

Table 4. Absolute Isometric Force Production of the Knee Extensors (n=19).

Condition	Baseline	0H	24H	48H	96H	
tMgCl$_2$ (N*m)	271 ± 83	239 ± 72	261 ± 68	278 ± 85	314 ± 90	
Placebo (N*m)	287 ± 73	246 ± 66	265 ± 73	274 ± 76	297 ± 85	
Total (N*m)	279 ± 78	243 ± 68**	263 ± 70	276 ± 80	305 ± 87**	
	F ratio	Num df	Den df	P value	AIC	Cond. R^2
Time	20	4	169	<0.001	1977	0.7961
Condition	2.0	1	169	0.229		
Time x Condition	0.3	4	169	0.888		
Mean ± SD						
* p<0.05 compared to baseline; ** p<0.01 compared to baseline						

Visual inspection of the raw torque between placebo and tMgCl₂ indicated a difference at baseline (Table 4). As such, leg dominance was added to the analysis and the full model was presented below (Table 5). The time x condition interaction was not significant (p=0.886), but the condition x leg dominance was significant (p=0.045). The full model had a slightly larger conditional R^2 and lower AIC, indicating a better model for these data.

Table 5. Full Model for Maximal Knee Extensor Isometric Force Production Adjusted for Leg Dominance (n=19).

Condition	Baseline	0H	24H	48H	96H	
$tMgCl_2$ (N*m)	275 ± 17	243 ± 17	266 ± 17	382 ± 17	317 ± 18	
Placebo (N*m)	283 ± 17	242 ± 17	260 ± 17	278 ± 17	310 ± 18	
Total (N*m)	279 ± 16	242 ± 16**	263 ± 16*	280 ± 16	314 ± 16**	
	F ratio	Num df	Den df	P value	AIC	Cond. R^2
Time	20.6	4	168	<0.001	1973	0.804
Condition	0.1	1	168	0.740		
Leg Dominance	8.0	1	168	0.005		
Time x Condition	0.3	4	168	0.886		

Marginal Mean ± SE
* p<0.05 compared to baseline; ** p<0.01 compared to baseline

There was a 12% decrease in torque when adjusting for leg dominance the 0H (-36.5, 95%CI [-52.1, -20.8], p<0.001) relative to baseline. At 24H, torque decreased by 5% in comparison to baseline (-15.9, 95%CI [-31.5, -0.2], p=0.049); but was similar to baseline at 48H (1.3, 95%CI [-14.4, 16.9], p=0.873) before a 12% increase by 96H (34.9, 95%CI [19.1, 50.8], p<0.001).

Because this was a pilot study and to maximize degrees of freedom, any non-significant group x condition interaction were removed and the reduced model was presented (Table 6). In the reduced model, there was a significant difference seen at the 0H (-36.5, 95%CI [-52.1,-20.8], p<0.001), 24H (-15.9, 95%CI [-31.5,-0.2], p =0.049), and 96H (35.0, 95%CI [19.1, 50.9], p<0.001) continued.

The marginal means between the full and reduced model did not greatly vary, which could be seen in the similar trend of the data between models. In comparison to the raw and full model, there was no difference in conditional R^2.

Table 6. Reduced Model for Maximal Knee Extensor Isometric Force Production Adjusted for Leg Dominance (n=19).

Condition	Baseline	0H	24H	48H	96H	
tMgCl$_2$ (N*m)	275 ± 16	243 ± 16	266 ± 16	282 ± 16	317 ± 16	
Placebo (N*m)	283 ± 16	242 ± 16	260 ± 16	278 ± 16	310 ± 16	
Total (N*m)	279 ± 16	242 ± 16**	263 ± 16*	280 ± 16	314 ± 16**	
	F ratio	Num df	Den df	P value	AIC	Cond. R^2
Time	20.9	4	172	<0.001	2004	0.807
Condition	0.1	1	172	0.742		
Leg Dominance	8.2	1	172	0.005		

Marginal Mean ± SE
* p<0.05 compared to baseline; ** p<0.01 compared to baseline

To confirm the influence of leg dominance on torque, peak torque values were normalized to baseline within subjects. The interaction of time x condition remained non-significant (p=0.375), confirming the full and reduced torque models. As expected, leg dominance was no longer a significant factor in the model (p=0.789). There was a trend for an effect of condition (2.7%, 95% CI [-0.1, 5.5], p= 0.058). There were significant decreases in relative torque at 0H (-12.8%, 95% CI [-17.2, -8.4], p<0.001) and 24H (-4.6%, 95% CI [-8.9, -0.2], p= 0.043); but no difference at 48H, as participants had returned to baseline output (-0.3, 95% CI [-4.7, 4.1], p= 0.888). At 96H, relative torque exceed baseline by nearly 4% (Table 6), but was not statistically significant (3.4, 95% CI [-0.9, 7.8], p= 0.125).

Table 7. Normalized Model for Maximal Knee Extensor Isometric Force Production (n=19)

Condition	Baseline	0H	24H	48H	96H	
tMgCl$_2$ (N*m)	100 ± 2	89 ± 2	98 ± 2	103 ± 2	103 ± 2	
Placebo (N*m)	100 ± 2	86 ± 2	93 ± 2	96 ± 2	104 ± 2	
Total (N*m)	100 ± 2	87 ± 2**	95 ± 2*	100 ± 2	103 ± 2	
	F ratio	Num df	Den df	P value	AIC	Cond. R^2
Time	15.7	4	175	<0.001	1488	0.215
Condition	3.6	1	175	0.058		

Marginal Mean ± SE
* p<0.05 compared to baseline; ** p<0.01 compared to baseline

Muscle Soreness

Following eccentric exercise, muscle soreness increased at 0H (26.6mm, 95% CI [20.1,

33.1], p<0.001) that remained elevated above baseline at 24H (22.1, 95% CI [15.6, 28.6], p<0.001)

and 48H time points (20.2, 95% CI [13.7, 26.7], p<.001). By the 96H time point, participants had

returned to baseline soreness (3.3, 95% CI [-5.5, 2.7], p = 0.510). $tMgCl_2$ slightly attenuated

perceived degree of soreness (17.6, 95%CI [11.7, 23.6]) in comparison to placebo (19.0, 95%CI

[13.0, 25.0]); however, this difference was not statistically significant (p = 0.510) (Figure 1).

Table 8. Perceived Muscle Soreness for Maximal Knee Extensor Isometric Force Production (n=19)

Condition	Baseline	0H	24H	48H	96H
$tMgCl_2$ (mm)	3.4 ± 4.2	29.1 ± 4.2	25.7 ± 4.2	23.0 ± 4.2	6.8 ± 4.2
Placebo (mm)	4.3 ± 4.2	31.8 ± 4.2	26.3± 4.2	25.1 ± 4.2	7.6± 4.2
Total (mm)	3.9± 3.4	30.5 ± 3.4**	26.0 ± 3.4**	24.0 ± 3.4**	7.2 ± 3.4

	F ratio	Num df	Den df	P value	AIC	Marg. R^2
Time	25.3	4	153	<0.001	1446	0.270
Condition	0.4	1	153	0.510		
Time x Condition	0.0	4	153	0.997		

Marginal Mean ± SE

* p<0.05 compared to baseline; ** p<0.01 compared to baseline

CHAPTER V: Discussion

Athletes commonly use supplementation for a competitive edge (Knapik 2016), yet the world of supplements is an ever-expanding market with little scientific backing to many of the products on shelves (Peeling et al. 2018). Magnesium (Mg), a mineral linked to more 300 enzymatic processes, may be linked to increased muscle force and could be used to improve recovery following unaccustomed exercise. However, there has been minimal work on the effects of a transdermal application of magnesium chloride ($tMgCl_2$) supplement and muscle performance. The purpose of this double-blind crossover study was to investigate the effects of a transdermal magnesium supplement on muscle force production recovery and perceived muscle soreness. Our major findings was that the use of $tMgCl_2$ appears to have minimal effect on recovery of knee extensor muscle torque following eccentric exercise, nor did it reduce the onset of muscle soreness in young, recreationally active men. These findings contradict our hypotheses that the use of this supplement would increase muscle force recovery and minimize perceived muscle soreness in comparison to a placebo. Under the current application protocol, this study suggests that $tMgCl_2$ has little apparent benefit, with the relatively small dosage being a possible reason for the lack of change.

Limitations and Strengths

To contextualize this study, the limitations and strengths of the study are described initially. We used recreationally active young males and these results and the application protocols used may not be generalizable to other populations. We were not able to determine if $tMgCl_2$ altered circulating levels. As only ~1% of the body's Mg is detectable in extracellular stores (Dean 2017, Jahnen-Dechent 2012), extensive tests must be used to assess total body Mg levels but were beyond the scope of this study. Besides subjective measures, we were not able to control dietary intake throughout the course of the study nor verify (other than verbal confirmation) that the participants were not active during the weeks of testing. We assessed the different conditions on opposite legs, which led to a difference in baseline strengths most likely due to leg dominance. While leg dominance was used as a covariate to adjust for this difference, the use of different limbs was deemed necessary as delayed onset muscle soreness and peak torque are both attenuated following even a single session (McHugh 2003, Nikolaidis et al. 2007). Being a pilot study, it now seems we were underpowered to discover this interaction effect. While we saw a trend, more subjects would be needed for these observations to be statistically significant.

Strengths of this study include the design, being a double-blind, randomized control trial performed in healthy men with previous resistance training experience. The use of a familiarization session and previous lifting experience likely permits a greater and more reliable effort to unaccustomed exercise and to control for learning effects but may have affected the torque and soreness responses. An estimate of total Mg applied to the muscles was also determined, which has not previously been reported (Gulick 2012).

Comparisons with Previous Literature

Muscle Force Recovery

We found that the use of $tMgCl_2$ provided no additional benefit in increasing muscle force recovery. In all three of the statistical models run (raw, full, reduced), the response following eccentric exercise was similar. There was a significant decrease in force production at the 0H and 24H time point that was gone by 48H. By 96H, a super compensation phase is apparent, as torque values exceeded baseline.

The reason for employing multiple models is that distinct difference between conditions for the baseline torque were observed. While there are several potential explanations, leg dominance seemed to be most likely. To fully test the effects of $tMgCl_2$ on recovery and soreness, it was necessary to use different legs for each condition. While rapid eccentric knee extensions were likely to be an unaccustomed stimulus, a second exposure to the same limb potentially confounds the results as soreness and muscle damage are attenuated following exposure (Clarkson 1992, Nikolaidis et al. 2007). These differences were better managed through normalization to baseline or including leg dominance as a covariate. In both the full and reduced models, leg dominance was a significant factor and when the data were normalized to baseline, the confounding effect of leg dominance was removed, as expected. Interestingly when compared to placebo, $tMgCl_2$ had a 4% increase in normalized peak torque by the 96H. While not statistically significant, an increase in force output of this magnitude in response to a single exercise session has potential to translate into improved athletic performance if these differences were sustained across multiple training sessions.

The eccentric exercise protocol used had previously been shown to elicit a 20% decrease in force and increased soreness (Hicks et.al 2016). Interestingly, the current study reports only a

12%, which may be due to a number of factors. The previously studied population was similar in age and being recreationally active, but they did not have a resistance training background (Hicks et. al 2016). Therefore, our population may have been more prepared to handle the rapid, lengthening contractions due to previous exposure to eccentric loading conditions during resistance training, thus producing an attenuated response. Also it is noteworthy to mention that while we attempted to account for leg dominance by utilizing a crossover design, this pilot study having a small sample size did not allow us to tease out the variability of this covariate. Thus when we examined the 96H time point for the full and reduced model we still saw a significant difference in comparison to baseline, but once we normalized the values the 96H time point was no longer statistically significant. This is not to say we did not see an increase in the marginal mean for $tMgCl_2$. Which eludes to there may be a slight increase in force production recovery at that time point, but we were too underpowered to detect it.

$tMgCl_2$ is understudied within the context of muscle performance, with only one previous study to our knowledge looking at a similar supplement (Gulick 2012) examined flexibility and endurance. However, oral supplementation and dietary intake has been investigated more thoroughly in regards to force production. Santos 2012 showcased the relationship between dietary magnesium intake maximal isokinetic knee extension and flexion torque in "elite" level basketball and handball players. Here they found that there was a linear relationship between dietary intake and their primary outcomes. However, it should be noted that there range for intake was from 100-500 mg. In comparison to our investigation, where we were only able to deliver 99 mg per application. In contrast, Setaro et al. 2014 found that in professional male volleyball players a 350mg/day dose for a month was not enough to elicit a significant response in knee extensor force production. There has also been positive effects seen in force production

with oral magnesium supplementation, but in untrained and/or older individuals (Brilla et al. 1992, Dominguez et al. 2006). The trend stays the same that higher Mg intake is linked to higher force outputs. Our investigation enabled the perspective of a transdermal approach to increasing force production with Mg supplementation.

Perceived Muscle Soreness

There is limited work on perceived muscle soreness and the use of magnesium supplementation, with this study being the first to our knowledge to examine this link. While Mg is known to be beneficial in alleviating pain in clinical populations (Schester et al. 2003, Yousef and Al-deeb 2013, Engen et al. 2015), it has not been investigated in a healthy and recreationally active populations. $tMgCl_2$ was shown to be not effective in minimizing perceived muscle soreness in our chosen population. As stated earlier, this could be due to the population's acclimatization to the severity of the protocol from their resistance training background. According to Hawker et al. 2011, the VAS values reported by our participants only place them in the category experiencing "mild pain" at their peak soreness. Coupled with the attenuated torque reductions, the eccentric load may have been insufficient for the population used and could have minimized the effects of $tMgCl_2$. However, the effect of soreness across time was consistent between our inquiry and previous literature. Hicks et al. 2016 showing a significant effect of time but no difference between groups (male and female). While we utilized a similar protocol, Hicks et al. 2016 reported the most significant soreness at the 24H time point, but we saw our most significant increase at 0H, which was unexpected. There was a slightly attenuated response between $tMgCl_2$ and placebo, but it was not statistically significant.

Implications and Future Studies

      Supplementation is a known aid for competitive performance (Peeling et al. 2018). There are numerous supplements available to the general public, and it is estimated to continue to grow exponentially (Gabriels 2013). As such, it is important that scientific evidence is available to investigate the claims being made by supplement manufacturers. Mg is necessary for various enzymatic process (Jahnen-Dechent et al. 2012) and has been thoroughly researched in terms of performance and oral intake and oral supplementation. It was hypothesized that transdermal supplementation would follow suit of its oral counterpart and increasing the amount of Mg available would enhance our desired outcomes of muscle force recovery and perceived muscle soreness by applying the Mg directly to the muscle. However, our results were statistically non-significant for conditions. While our findings were not what we hypothesized, we were able to provide a deeper knowledge to the anecdotal claims of $tMgCl_2$. While not statistically significant, we did see a slight favoring of $tMgCl_2$. These findings suggest that there is potential benefit in the micro-cycle of training, which could possibly lead to greater gains in the mesocycle and macrocycle. While we did not find a significant effect of utilizing ~100 mg per application of $tMgCl_2$, it may be necessary to examine higher dosages in the future. As stated earlier, while there has been research that has examined the effects of dietary or magnesium intake or oral supplementation on performance, there is a paucity of research on the effects of transdermal application on performance such that firm conclusions are not possible at this stage. Under the current conditions, $tMgCl_2$ does not appear to be as beneficial as previously hypothesized. However, more research is warranted before making firm conclusions (Peeling et al. 2018).

Conclusion

In conclusion, many ergogenic aids aimed at increasing performance are supported by no more than anecdotal claims. Based on previous literature showcasing the positive effects of dietary intake and oral Mg supplementation on force production, soreness and pain; we hypothesized that $tMgCl_2$ would enhance force production recovery and minimize perceived muscle soreness. Our investigation indicates no effect of $tMgCl_2$ for both perceived muscle soreness and muscle force recovery. The eccentric load used may have been insufficient, as evidenced by the attenuated torque loss and soreness relative to previous work (Hicks 2016), and thus may have minimized any benefits of $tMgCl_2$. Future investigations should consider using higher dosage $tMgCl_2$ or possibly an untrained population.

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