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THE BENEFITS OF THERAPEUTIC ULTRASOUND FOR IMPROVING RECOVERY OF COLLEGIATE SOCCER PLAYERS IN BETWEEN FRIDAY AND SUNDAY MATCHES

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ABSTRACT

Collegiate soccer athletes face physical and physiological stressors during match play that can lead to ailments such as inflammation, muscle soreness, decreased range of motion, and skeletal muscle damage. Through the use of evidence-based studies coaches, trainers, and collegiate soccer athletes can determine best practices for optimized recovery in a collegiate soccer setting. One of the lacking supplemental recovery modalities in collegiate soccer is therapeutic ultrasound. Therapeutic ultrasound is a machine that utilizes vibration and thermal effects to help decrease skeletal muscular damage, reduce soreness of skeletal muscles, improve blood flow, and increase relaxation of the muscles. Therapeutic ultrasound in congruence with a holistic, and well-rounded recovery plan including proper nutrition, appropriate water intake, and adequate sleep can lead to optimized recovery for collegiate soccer athletes. By gaining more information through research and supplemental data collection, health professionals, coaches, and athletes will be better informed about the physiological benefits that therapeutic ultrasound possesses for collegiate soccer athletes as well as athletes of other endurance and power related sports.

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Chapter 1: Introduction

There is a significant gap in knowledge of the potential benefits of therapeutic ultrasound utilized in collegiate soccer settings. This rehabilitative modality does result in increased blood flow, decreased inflammation, decreased muscle damage, and increased range of motion for joints and skeletal muscles through the utilization of internal heating effects (Lintonbon, 2016). These aforementioned ailments are prevalent in collegiate soccer settings because of the high demand that this sport places on the bodies of the athletes. Because of this it is important to understand the mechanism of therapeutic ultrasound and how in combination with a well-rounded and individualistic recovery program, collegiate soccer player may experience accelerated and improved recovery.

Male collegiate soccer is one of many sports within the National Collegiate Athletic Association (NCAA) with nearly 25,000 men's soccer athletes nationwide that compete across three divisions (DI, DII, DIII) (Anderson et al., 2021). The annual schedule includes a fall competition season across ten to fourteen weeks with twenty games per season. Weekly schedules typically include two games per week, Friday afternoon and Sunday mid-day, with 90-minute matches, not including any over time (typically an additional 20 minutes). Each NCAA match includes two forty-five-minute halves with one fifteen-minute half-time, and unlimited substitutions (Anderson et al., 2021). Collegiate soccer demands aerobic fitness, anaerobic fitness, muscular strength, and muscular endurance (Nédélec, 2012). These demands place physiological stress on the body and impose adaptive responses of the hypothalamic-pituitary-adrenal (HPA) axis (Smith & Vale, 2006).

The HPA axis is responsible for responding to physical stress on the body such as damaging of skeletal muscle, improving cardiovascular function, and decreasing inflammation

through immune responses (Smith & Vale, 2006). The process of responding to physical stress occurs by the HPA axis releasing corticotropin-releasing factor (CRF) which binds to the anterior pituitary of the brain causing a release of adrenocorticotropic hormone (ACTH) (Smith & Vale, 2006). ACTH then travels to the adrenal cortex of the brain to stimulate glucocorticoids which aid in decreasing inflammation, controlling metabolic functions of cells, and regulating cardiovascular function in a physically stressful situation of a collegiate soccer match (Nédélec, 2012; Smith & Vale, 2006). Another important natural response to physiological and physical stress is the activation of the sympathetic adrenal medullary (SAM) system which is also known as a "fight or flight" response (Birditt et al., 2018). This SAM system leads to the release of catecholamines which include epinephrine and norepinephrine from the adrenal medulla (Birditt et al., 2018). Catecholamines enter into the blood stream during an acute stress incident or to parts of the body to elicit a physiological reaction to that stressful stimulus (Birditt et al., 2018). Short-term activation of both the HPA and SAM pathways are crucial for exercise as this increases heart rate, blood pressure, and blood glucose levels. However, chronic activations of these pathways can lead to impairments in overall health and physical performance, which is why recovery is extremely imperative for the human body (Birditt et al., 2018; Smith & Vale, 2006).

Evidence-based findings determine best practices for recovery in collegiate soccer. The goal of the evidence-based findings includes mitigating both physiological and physical stressors. Strategies for evaluating these stressors include measuring athlete workload throughout a match to then apply these objective findings to the recovery strategies of the athletes (Kupperman et al., 2021). Global Positioning Systems (GPS) and accelerometry microtechnology provide objective information about the external workload of a collegiate

soccer athlete and can aid in making informed decisions about recovery strategies for athletes between matches because this information provides data such as total distance covered, sprint distance, top speed reached, and number of explosive efforts (Gomez-Carmona et al., 2020; Lamond et al., 2018; Yli-Piipari, 2019). In addition to the common use of GPS and accelerometry microtechnology to gather objective match play data to understand physical demands, another component to this continued research on how match play data can inform recovery strategies is understanding how external load demands may lead to common injuries or ailments, ultimately hindering performances. For example, a study conducted by Cross et al. (2015) researched musculoskeletal injuries specifically evaluating hamstring strains. This Cross et al. (2015) study evaluated both workload and incidence of injury, in attempt to find relationships that can help coaches better understand how the demand of sport may influence injury rates.

Hamstring strains are common in competitive soccer and occur when the muscles are overloaded with pressure while the leg is in a fully stretched position with the weight of the athlete's body pressing down (Cross et al., 2015). Because this type of strain is common during collegiate soccer matches, it is important for athletic personnel to understand the mechanism of injury to preemptively optimize recovery efforts in an attempt to reduce overall risk. Collegiate soccer athletes suffering from a hamstring strain can miss an average of three matches with symptoms including skeletal muscle damage, decreased range of motion, and inflammation (Kupperman et al., 2021). Cross et al. (2015) discovered that male collegiate soccer players took around seven days to recover from first-time strains and around eleven days to recover for recurrent instances of hamstring strain. The rehabilitation process includes active recovery with completion of low intensity exercises, slow progression of these exercises within appropriate

time frames and are typically implemented by athletic trainers and physicians (Cross et al., 2015). Another study pertinent to this topic assessed deltoid ligament sprains within the ankle joints of collegiate soccer players (Kopec et al., 2017). A sprain, or structural damage of this deltoid ligament can restrict skeletal muscle motion and increase inflammation of the surrounding skeletal muscles (Kopec et al., 2017). Deltoid ligament sprains can be common during match play and can result in one to six days of recovery (Mansfield et al., 2013; McCollum et al., 2013). Rehabilitation and recovery processes include strengthening of skeletal muscles, improving range of motion, and increasing ligament stability for the collegiate athlete (Kopec et al., 2017).

These studies conducted by Kupperman et al. (2021), Cross et al. (2015), and Kopec et al. (2017) are helpful in describing common stressors and occurrences that happen in collegiate soccer and identifying the general recovery from injury strategies that are typically used. Some examples of recovery strategies utilized in the aforementioned studies included low-intensity resistance exercises, static stretching strategies, and the use of therapeutic modalities. Therapeutic modalities that are commonly found in recovery settings and in collegiate soccer are heating pads, icing injured areas, electrical stimulation, and cryotherapy (Desmeules et al., 2015). One commonality amongst the current available studies that is specific to collegiate soccer is the absence of therapeutic ultrasound as a researched recovery modality option (Cross et al., 2015; Kopec et al., 2017; Kupperman et al., 2021).

Therapeutic ultrasound is a non-invasive modality utilized in the field of rehabilitative sciences that applies sound waves at different frequencies to penetrate the tissues of the skin and promote increased blood flow, decreased inflammation, decreased muscle damage, and increased range of motion for joints and skeletal muscles using internal heating effects (Lintonbon, 2016).

The aforementioned studies (Cross et al., 2015; Kopec et al., 2017; Kupperman et al., 2021) discussed the occurrence of skeletal muscle damage, inflammation, and decreased range of motion following these common injuries in collegiate soccer. However, recovery in collegiate soccer is not solely about the stressors and physiological damages that occur, although this is an extremely important component of recovery. Recovery also includes adequate nutrition, sleep quality, and hydration status as important components of a more holistic recovery for collegiate soccer athletes (McArdle et al., 2015; Nédélec, 2013). Nutrition, sleep, and hydration also assist the processes to turn off the stress responses of the HPA and SAM pathways (Smith & Vale, 2006; Birditt et al., 2018).

With the implementation of therapeutic ultrasound, men's collegiate soccer teams may reduce recovery times and optimize recovery strategies (Nédélec, 2012). Because there is a lack of research on the effects of therapeutic ultrasound, especially in reputable sources like the *Journal of Athletic Training*, or journals supported by the American Physical Therapy Association (APTA), it is difficult to determine what effects therapeutic ultrasound would have on male collegiate soccer athletes specific to recovery efforts between Friday and Sunday matches. These stressors and physiological hinderances of inflammation, skeletal muscle damage, and decreased range of motion occur in collegiate soccer so it can be rationally concluded that therapeutic ultrasound may help to optimize the recovery of collegiate soccer athletes. The following literature review will assess the benefits of therapeutic ultrasound and I will propose a future research study with the intention of filling the current gap in the literature regarding what is known about the use of therapeutic ultrasound for recovery between soccer matches.

Chapter 2: Review of the Literature

2.1: Definition of Recovery

The term "recovery" is often utilized ambiguously in sports, and there are a variety of definitions for "recovery" due to differences in an individual's education or professional training. Some variables are subjective such as relative soreness and relative fatigue of the individual (Hammond et al., 2013). Other parameters are more objective such as ability to maintain average running speed and average VO_2 values (a measure of aerobic capacity) from Friday matches to Sunday matches (McArdle et al., 2015). After completing these matches, it is also important to measure heart rate, blood pressure, and blood glucose levels all returning to homeostatic levels. Different professionals in the field of exercise science are trained differently leading to various uses of the word recovery in a collegiate soccer setting (Hammond et al., 2013). The specific definition of recovery will dictate the parameters of recovery methods and when an individual will be able to begin exercising again. One way to clearly define and view recovery in a collegiate soccer setting and avoid discrepancies in definitions is to implement player questionnaires to achieve subjective data on how the athlete is feeling in between matches (Hainline et al., 2017; Moseley et al., 2018). The available literature argues in favor of the important procedure of determining session rate of perceived exertion (sRPE) post-match and general questionnaires with Likert scales measuring overall fatigue for athletes on a day-to-day basis (Hainline et al., 2017).

2.2: Definition of Recovery in Collegiate and Professional Soccer

In this literature review recovery will be defined as the ability to sustain range of motion, repair muscle microtrauma developed in collegiate soccer games, decreased inflammation and level of muscle soreness. Certain measurements that can be used to aid in recovery decisions

include the work completed by the athlete, nutrition throughout the day, water intake, sleep time and quality, and any supplemental therapeutic modalities used (McArdle et al., 2015). It is important to enhance the recovery process by having trainers, physicians, and coaches conversing with the athlete about implementing certain strategies to mitigate stressors such as soreness, fatigue, decreased range of motion, and muscle microtrauma. Implementation of a variety of strategies may lead to higher outputs and intensity levels during training sessions (McArdle et al., 2015). One of the recovery strategies for collegiate soccer athletes that is lacking in academic research is the use of a therapeutic modality that us commonly used in physical therapy settings: therapeutic ultrasound. The recovery of collegiate soccer players includes many different strategies that can be optimized with the help of therapeutic ultrasound to sustain range of motion, repair muscle microtrauma caused in collegiate soccer games, decrease inflammation, and decrease levels of muscle soreness.

For collegiate soccer athletes, recovery from training sessions and matches may look different compared to other sports. Soccer is a physically demanding sport that includes a variety of activities such as running, sprinting, jumping, and change of direction which requires frequent acceleration and deceleration efforts. The intensity of collegiate soccer matches, in conjunction with the known physical demands of the sport, contributes to high levels of fatigue among collegiate soccer players (Nédélec, 2012). Fatigue of soccer players is generally accepted as a decrease in muscle performance during intense periods of exercise and is associated with a sensation of tiredness and weakness (Brownstein et al., 2017; Nédélec, 2012).

Along with the high intensity work done throughout matches or practice there are other factors that contribute to the decline in performance of soccer players: dehydration, glycogen depletion, muscle damage, and mental fatigue are all factors that will cause post-soccer match

related fatigue (Nédélec, 2012). The fatigue caused by match play persists beyond the acute exercise bout and can take many days to resolve especially when there are infrequent or minimal recovery periods between matches. One of these factors, muscle damage, is very important to consider due to the variety of muscles repeatedly utilized throughout a match. There are many eccentric muscle contractions, or increased tension during lengthening of the muscle to its resting position which causes microtrauma at the cellular level, that occur during sports such as soccer (McArdle et al., 2015). These movements have the potential to induce muscle damage or mechanical disruption of muscle fibers. This may be apparent due to either one or a combination of the following: inflammation of a particular area, increased soreness of the body or localized joint area, and reduced joint range of motion. The severity of the damage on the individual's muscle may delay repair of the muscle as well as time to recover properly (Nédélec, 2012).

Muscle damage may also be more apparent and concerning for collegiate and professional soccer athletes because the time in between games (typically 42 to 48 hours) is shorter compared to recreational level activities to fit more games into a season, which provides a relatively quick recovery time for the athletes to address muscle damage, dehydration, glycogen depletion, muscle fatigue, and mental fatigue (Nédélec, 2012; Silva et al., 2018). These aforementioned physiological issues are very important to consider especially when collegiate and professional soccer athletes are training and practicing in between these matches (Silva et al., 2018).

If these training sessions are excessively focused on cardiovascular fitness and match-like intensities, it may not give the players enough time to recovery properly between matches (Silva et al., 2018). Excessive training sessions increase injury rates among these soccer players especially during a very congested season (Silva et al., 2018). This is also not just a decrease in

performance, this can include increased presence of infection, increased muscle soreness, and a potential loss of interest of performing at an elevated standard (McArdle et al., 2015). However, there must be a balance of players experiencing 'real' muscle physiological strain that occurs during a match and recovery during practice sessions (Silva et al., 2018). This balancing act must be carefully monitored to prevent both sympathetic and parasympathetic forms of overtraining. Sympathetic overtraining is generally seen as hyperexcitability and restlessness while parasympathetic overtraining includes greater effort for the athlete to maintain performance which decreases physical performance overtime (McArdle et al., 2015). These training and recovery sessions must implement both acceleration and deceleration impact for the players instead of just conducting unidirectional sessions (Silva et al., 2018). These training strategies, implemented by coaches and athletic trainers, along with soccer related movements such as kicking and jumping, can help stimulate and replicate workloads associated with match play. However, this must still be in line with helping the athletes return to match play following a competition and allowing them to recover optimally.

It is also very important when evaluating recovery of a soccer athlete to determine whether the individual had completed a live match and if so, how many minutes were played during the match. Match play time is important to understand because it is going to be different across athletes on the same team. The players that played a full ninety-minute match may need a longer time frame to recover than an individual who may have only played the last ten minutes of the game. This may lead the individual athletes to require different types of recovery strategies based on the relative levels of intensity compared to regular training sessions (Nédélec, 2013). In a study conducted to determine neuromuscular fatigue, and the resulting recovery time frame, Brownstein et al. (2017) found that competitive soccer matches cause considerable damage to

both the central nervous system and overall muscular function requiring up to forty-eight hours to recover from. The study evaluated sixteen male semi-professional soccer players from Level 9 of the English Football League (Brownstein et al., 2017). Brownstein et al. (2017) investigated these athletes after a ninety-minute competitive soccer match was completed with all the participants playing the entirety of the match. They measured neuromuscular, physical, and perceptual variables before and after the match at 24, 48, and 72 hours after the conclusion of the match (Brownstein et al., 2017). These assessments included perceptual response to how fatigued the players felt, muscular force of the athlete's quadriceps measured during an isometric maximal voluntary contraction of the knee extensors, motor nerve response and stimulation based on the active motor threshold, and physical function through the employment of jumps, countermovement jumps, and reactive strength for a drop jump (Brownstein et al., 2017).

Brownstein et al. (2017) recorded subjective player fatigue, neuron response for muscle contraction, and individual physical function and strength in power movements and concluded that soccer matches impair activation of the central nervous system and potential twitch force of the quadricep muscles, which is the potential of a single contraction to occur for the stimulated muscle. These impairments required at least forty-eight hours to resolve among the participants (Brownstein et al., 2017). As stated previously by Nédélec (2012) and Silva et al. (2018), typical time between games is forty-two to forty-eight hours which means recovery needs to be optimized as much as possible to make sure that collegiate soccer players are fully recovered before the next match. Brownstein et al.'s (2017) research is important to utilize in the recovery of soccer athletes because it is concerned with improving recovery procedures for these athletes to increase performance and decrease the likelihood of injuries. The body does incur damage throughout a soccer match and recovery is not just limited to improving neuromuscular, physical,

and perceptual function. Because of the increased likelihood of decreased physiological performance following a collegiate soccer match, it is vital that there are physiological and beneficial recovery strategies in place to aid and expedite the athlete's recovery within this forty-eight-hour window.

Along with central nervous system activity it is important to remember the physical demands that collegiate soccer can place on the body of an athlete (Smith & Vale, 2006). By having the HPA axis responding to both psychological and physical stress in the body damaging of skeletal muscle, decreased cardiovascular function, and inflammation can all be mitigated (Smith & Vale, 2006). The HPA axis eventually leads to the adrenal cortex of the brain stimulating glucocorticoids which aid in decreasing inflammation, controlling metabolic functions of cells, and regulating cardiovascular function in a physically stressful situation of a collegiate soccer match (Nédélec, 2012; Smith & Vale, 2006). Collegiate soccer athletes are subjected to physically and psychologically stressful situations which is possibly why Brownstein et al. (2017) saw decreases in central nervous functioning. The nervous system of the athlete is constantly subjected to the stressful situations which may lead to over stimulation of the HPA axis, decreasing the efficiency of this system over time (Smith & Vale, 2006).

2.3: Recovery Strategies for Collegiate Soccer Athletes

Recovery strategies for soccer players can be individualized to athletes but there are certain standards in nutrition, sleep, and hydration that are vital to a holistic recovery of the athlete. This holistic approach allows for the entire body to recover and can improve physiological performance. By maintaining consistency and communication among athletes, coaches, trainers, and nutritionists', collegiate soccer players will be provided with the building blocks to achieve a well-rounded recovery program. However, along with these standard

strategies there is always room for improvement in optimizing recovery for collegiate athletes. This can include clinical and therapeutic modalities that will aid in the physiological recovery of collegiate soccer players.

One of the most important strategies for exercise and athletic recovery is a proper nutritional plan following intense training sessions and matches. A proper or optimal diet for collegiate soccer players supplies both micronutrients and macronutrients in adequate numbers for the body to use in maintenance, repair, and growth without overly excess food intake (McArdle et al., 2015). Macronutrients include carbohydrates, lipids, and proteins which are consumed in large quantities, while micronutrients include vitamins and minerals like Vitamin A, Vitamin B, calcium, and phosphorus which are consumed in small quantities (McArdle et al., 2015).

Collegiate soccer players' bodies are possibly dehydrated and depleted of glycogen stores which need to be replenished to provide the body with a renewed source of energy (McArdle et al., 2015; Nédélec, 2013). Glycogen is a stored carbohydrate within the liver and muscle that can be broken down into glucose through the process of glycogenolysis. Carbohydrates including glycogen play an important role in providing the body with both readily available energy and stored energy (McArdle et al., 2015). Carbohydrates have four main roles in the human body which include an energy source during intense exercise, sparing the breakdown of tissue proteins, a primer for fat oxidation, and fuel source for nerve tissue in the central nervous system (McArdle et al., 2015; Nédélec, 2013). During an intense and one-hour duration exercise, liver and muscle glycogen stores are depleted at a rapid pace with more moderate and prolonged exercise utilizing fat as the main energy source. A carbohydrate deficient diet will lead to low levels of liver and muscle glycogen which negatively impact the short-term and prolonged

exercise activities of an individual (McArdle et al., 2015). Collegiate soccer players are constantly required to employ quick bursts of speed to get to the ball first which is aided by the presence of carbohydrates in the body due to this being a quick anaerobic process (Nédélec, 2013). Therefore, a diet with proper amounts of carbohydrates is imperative for a collegiate soccer athlete. Appropriate amounts of carbohydrates will differ from person to person but for a collegiate athlete a good baseline value is around 8 to 10 grams, in an unrefined form, per kilogram of the athlete's body mass (McArdle et al., 2015).

Lipids are also very important in the diet of collegiate soccer and consist primarily of triglycerides that contain one glycerol and three fatty acid chains (McArdle et al., 2015). Lipids can be broken down into saturated and unsaturated fatty acids with unsaturated fatty acids differing from saturated fatty acids by possessing at least one double bonded carbon resulting in the fatty acid being liquid at room temperature (Lotfi et al., 2020; McArdle et al., 2015). The four major roles of lipids in the body include being a transportable and available energy source, protecting vital organs, thermal insulation, and acting as a hunger suppressor (McArdle et al., 2015). During light to moderate intensity exercise lipids provide the most energy for completion of the exercise. This can include a steady state jog or low-intensity jog, which both occur during collegiate soccer matches. With regular aerobic exercise an individual can improve lipid oxidation which is breakdown of lipids to be used as energy for the body (McArdle et al., 2015). As stated previously, as prolonged exercise continues this will deplete muscle and liver glycogen stores resulting in the catabolism or breakdown of lipids in the body (Lotfi et al., 2020; McArdle et al., 2015). Collegiate soccer athletes participate in a ninety-minute soccer game with a large quantity of that time spent jogging at a steady rate. The energy source responsible for providing energy in this state are lipids which is why proper amounts of lipids in a collegiate soccer

athlete's diet is so important (Lotfi et al., 2020). If limited amounts of lipids are present, the body may need to resort to other energy sources in the body or lead to a decrease in exercise performance for the athlete. There is no standard amount of lipids that an individual needs to consume but for optimal health the intake should not exceed 25 to 35 percent of total calorie intake (McArdle et al., 2015).

In addition to carbohydrates and lipids, proteins also play a vital role in an individual's ability to conduct and maintain differing levels of exercise. Along with regulating acid-base characteristics of bodily fluids and serving as the primary component of plasma membranes, proteins are also involved in structural components that play an important role in muscle contraction and relaxation (McArdle et al., 2015; Moya-Amaya et al., 2021). Amino acids are the primary building blocks of proteins and one of the most important amino acids is leucine. Leucine is an essential amino acid that is responsible for rate of muscle protein synthesis, promoting muscle growth, and aiding in recovery of muscle tissues (McArdle et al., 2015). Protein synthesis involves transcription, the copying of a section of DNA in a cell's nucleus to create a single strand of RNA which is then translated, whereby the RNA codons are formed into specific amino acids in the cytoplasm of the cell to form proteins (McArdle et al., 2015). During strenuous exercise there is an increase in protein breakdown of the body with increase in the synthesis of protein during recovery from the strenuous exercise. Heightened levels of proteins in the body help repair the microscopic muscular damage caused by the exercise and can increase the size and strength of the muscle (McArdle et al., 2015; Moya-Amaya et al., 2021). This is very important in collegiate soccer because these are strenuous activities that result in muscular damage. To repair these damages, collegiate soccer players must consume a proper amount of protein to facilitate muscular structure. Intensely training athletes like collegiate soccer players

should consume between 1.2 to 1.8 grams of protein per kilogram of body mass daily (McArdle et al., 2015). This will vary with the type of exercise the athletes are conducting; increases in resistance training may induce a need for increased levels of protein consumption (Moya-Amaya et al., 2021).

Additionally, micronutrients play very important roles in facilitating energy transfer and tissue synthesis and include both vitamins and minerals (McArdle et al., 2015). Vitamins, for example, serve as links and regulators in metabolic reactions and help protect the plasma membranes of the body's cells (McArdle et al., 2015). Minerals such as calcium and phosphorus can provide structure of bones, maintain normal bodily functions, and help modulate cellular activity within metabolism (McArdle et al., 2015). Both macronutrients and micronutrients serve important roles in the body which is why nutrition of a collegiate soccer athlete is so important. Without these nutrients an individual's performance would decrease over time and without a proper nutrition plan the athlete may never perform as optimally as possible. With a sport such as soccer that possesses such high physiological demands on athletes it is important to not worry about consuming too much food. A worry of overindulging may lead to Relative Energy Deficiency in Sport (RED-S) which is a term describing an individual who trains intensely and is not fueling the body properly to promote weight loss. This can impair growth, harmfully impact overall health, and decrease effects physical performance (Stenqvist et al., 2021). However, proper nutrition and education for athletes with unique nutritional needs can help decrease the prevalence of RED-S in collegiate and professional sports (Stenqvist et al., 2021).

One of the best ways to determine an if an athlete is consuming the proper amount of food is by utilizing a metabolic cart to conduct a resting metabolic rate test. The metabolic cart is a machine that displays the resting exchange ratio (RER) which is the ratio between production

of carbon dioxide and consumption of oxygen (Haff & Dumke, 2012). The RER calculates the resting metabolic rate (RMR) of an individual which is the metabolism of the athlete and the basic needs that the athlete requires to function properly (Haff & Dumke, 2012). The machine measures the metabolic rate of the individual which is the number of calories needed to function every day with little to no movement. Utilizing the metabolic cart can help determine nutritional needs based on type of sport, physical activity, calories burned in exercise, and goals of the individual. Based on the RMR data retrieved for a collegiate soccer athlete, along with a nutritionist or exercise scientist, can determine the athlete's individual nutritional program. There is not a universal nutrition approach for these athletes; each athlete requires specific macronutrients and micronutrients, as well as optimal gastric emptying based on nutrient timing.

Sleep is also a very essential and important part of recovery for soccer athletes because when an athlete has adequate sleep this reduces pain from muscle soreness and improves in athlete's mental fatigue (Nédélec, 2013). During a soccer match players are required to employ both high physical activity and mental focus to perform the most optimally. With increased stress during the game, which is higher than throughout the day, it can be difficult to fall asleep. This may result in irregular sleep cycles that decrease the quality of sleep. As previously mentioned, sympathetic overtraining, which is generally seen as hyperexcitability, and restlessness can also cause collegiate soccer players to remain awake for longer periods of time, decreasing time and quality of sleep (McArdle et al., 2015). The athlete's sleep may also be affected by reduced muscle glycogen content, consuming too much water, and muscle soreness (Nédélec, 2013). This muscle soreness can then be amplified as a night of sleep deprivation can cause enhanced inflammatory responses from the skeletal muscles of the athlete (Nédélec, 2013). One of the ways to prevent muscle soreness is to restore muscle glycogen stores by consuming a meal or

snack high in carbohydrates. Following proper consumption of food, it is advised for the player to have a schedule for going to sleep that includes the same procedures every night such as brushing teeth, being in a dark and quiet room, or listening to relaxing music (Nédélec, 2013). However, certain activities that can lead to sleep disturbances include consumption of caffeine before the match, consumption of alcohol after the match, or consumption of too much liquid after the match (Nédélec, 2013). Because of the varied schedule of collegiate soccer athletes, it is important to educate them on the importance of short naps. This can be a thirty-minute nap followed by a modality of recovery, such as stretching, which can help with physical performance and compensate for a night of lost sleep. However, the most important aspect for sleep among these athletes is to schedule and plan sleep schedules to restore good sleep for the players (Nédélec, 2013). This will help the athletes be more aware of life schedules and recognize the importance of sleep.

Along with nutrition and sleep, a collegiate soccer athlete must be aware of the amount of water that they are consuming over the course of the forty-eight-hour recovery period. Ingesting water before and during exercise will help diminish effects of dehydration with optimal amounts being 400 to 600 mL of fluid before exercise and 250 mL every fifteen minutes of exercise (McArdle et al., 2015). This is also under very ideal situations with water readily available which in a ninety-minute soccer match may not always be the case. During intense physical activities individuals should consume around 5 to 10 liters of water daily depending on the intensity and duration of exercise (McArdle et al., 2015). These physical activities increase sweating and water requirement of the body, but improper consumption of water to replenish these needs can lead to hyponatremia which is an osmotic imbalance in the blood-brain barrier that causes a rapid increase in water to the brain. Hyponatremia can lead to swelling of the brain and can cause

headaches, confusion, and nausea (McArdle et al., 2015). This condition of hyponatremia can be caused by excessive fluid intake, failure to excrete fluids, inadequate sodium intake, and excessive sodium loss during exercise (McArdle et al., 2015). It is important that after the completion of a match or practice that collegiate soccer players consume the proper amount of water that correlates with the individuals' physiological needs. Along with these standards of proper nutrition, good sleep, and adequate water intake there are other modalities of recovery that offer other physiological benefits to aid and expedite the recovery process for these athletes.

An example of a supplemental recovery modality is therapeutic ultrasound, which is a machine that utilizes vibration and thermal effects to help decrease skeletal muscular damage, reduce soreness of skeletal muscles, improve blood flow, and increase relaxation of the muscles (Lintonbon, 2016). Therapeutic ultrasound is applicable to collegiate soccer because of the specific issues that this modality addresses in collegiate soccer athletes such as skeletal muscle damage, skeletal muscle soreness, and a heightened sympathetic nervous system post-match. This modality is relatively portable for traveling teams and does not take hours to conduct on an individual. With only forty-eight hours to recover, the introduction of a beneficial and effective modality may improve collegiate soccer athletes' recovery process, thereby improving the athlete's physical performance during training and match-play.

2.4: Therapeutic Ultrasound

Therapeutic ultrasound is the use of sound waves at different frequencies, which are caused by electrical effects of vibrating materials, to penetrate the tissues of the skin which promotes increased blood flow, decreased inflammation, decreased muscle damage, and increased relaxation of muscles through internal heating effects (Lintonbon, 2016). The beginnings of ultrasound technology can be dated back to the 1880's when Pierre and Jacques

Curie tested the effects of vibration on quartz crystals, which was later developed to visualize underwater surroundings and impurity testing of metals (Bachu et al., 2021). This is due to the high frequency sound waves of the technology that are broadcast, and the echoes are analyzed to produce an image of the observable area. This is akin to ultrasonography which utilizes the same properties to examine internal organs (Bachu et al., 2021). Eventually, ultrasound technology was introduced to the medical and clinical setting to view developing fetuses as well as to measure bone mineral densities of individuals (Bachu et al., 2021).

In the 1930's, a group of scientists including H. Freundlich and K. Collner discovered the natural thermal effects of ultrasound on human tissue, which marked the historical beginning of ultrasound being utilized therapeutically (Bachu et al., 2021). The physical interaction between the ultrasound waves and the tissues of the human body displays promising clinical and therapeutic applications to those suffering from physical ailments. These ailments can include those who suffer muscle tightness, broken bones, and healing scar tissue (Jenne et al., 2012). Interactions with the body include ultrasound waves penetrating the skin and tissues without damaging tissue along with thermal heating (Jenne et al., 2012). Therapeutic ultrasound is utilized frequently in physical therapy clinics to treat several injuries and symptoms such as musculoskeletal disorders of muscle pain, general pain, stiff joints, and injuries of tendon and ligament tissue. (Morishita et al., 2014).

The therapeutic modality of ultrasound is implemented with the use of a machine with a probe attachment containing small crystals within the head of the probe. Therapeutic ultrasound is the sending of ultrasound waves, which are caused by a piezoelectric effect from the vibrations of crystals in the head of the probe into the tissues of the skin. Electrical energy travels through the probe causing the crystals to vibrate, which in turn sends the ultrasound waves through the

skin (Lintonbon, 2016). These waves produce thermal energy deep in the tissue of an individual with no sensation of heat felt by the patient. A clinician, such as a physical therapist, applies the probe directly to the skin with a Myogel barrier applied on the target area to decrease friction, as well as help the ultrasound waves travel into the skin (Lintonbon, 2016). During application, the head of the ultrasound probe is kept in a constant motion to not cause the patient any discomfort. Some modifiable parameters associated with therapeutic ultrasound are frequency/intensity, treatment time, and treatment area (Morishita et al., 2014). The normal frequency ranges utilized for therapeutic ultrasound are around 1-3 MHz to either facilitate the thermal or nonthermal effects of this modality (Lintonbon, 2016; Morishita et al., 2014). Treatment time and treatment area will differ depending on the type of recovery, type of injury, and goals for treatment of the patient (Lintonbon, 2016; Morishita et al., 2014).

The desired outcomes of therapeutic ultrasound include increased blood flow to the specific area, reduction of swelling, and assistance with bone fracture recovery. The available literature indicates that muscle injuries, ligament injuries, and bone injuries of the knees, trapezius, tibial, and vertebrate such as spondylolysis can benefit from therapeutic ultrasound (Lintonbon, 2016; Morishita et al., 2014; Yang et al., 2017). Additional research indicates the positive effects of therapeutic ultrasound on individuals of varying ages experiencing muscle stiffness and joint range of motion (Morishita et al., 2014). Therapeutic ultrasound is not only a viable option for improving muscle stiffness among physical therapy patients with acute musculoskeletal injuries, but also a viable option for increasing cellular components such as improving fibroblast proliferation or skin cell proliferation (Yang et al., 2017). The use of ultrasound to increase cellular components led to wound healing of individuals who received therapeutic ultrasound treatment. However, more research is warranted to determine the long-

term benefits of ultrasound, especially in the scope of musculoskeletal recovery of an individual (Page et al., 2021). The research on therapeutic ultrasound for elite athletic populations specific to recovery is only one small subset of the research on ultrasound technology (Yim & Corrado, 2012). However, this information is critical in uncovering the physiological benefits of therapeutic ultrasound on athletic and normal individuals. This will hopefully facilitate and increase recovery rates among those with physical ailments of the body. The overall well-being of an individual is very important and therapeutic ultrasound may offer solutions for collegiate soccer players to recover from injuries or everyday muscle soreness.

2.5: Benefits of Therapeutic Ultrasound

As previously described, collegiate soccer athletes endure high amounts of both aerobic and anaerobic physical activity during matches and during practice, which can lead to fatigue, muscle soreness, and mechanical disruption of muscle fibers (McArdle et al., 2015; Nédélec, 2012). To improve overall aerobic and anaerobic performance of these athletes, specifically the ability to recover and be ready to perform with a quick turn-around between matches (average period is 42 hours), it is important for trainers and coaches to implement worthwhile recovery strategies and techniques to facilitate an effective recovery for these athletes (Nédélec, 2013). One of the ways in which these athletes can experience a worthwhile recovery is with therapeutic ultrasound in the hands of a clinician (Hotfiel et al., 2018). This type of modality may offer unique qualities and functions that can aid these athletes in day-to-day recovery from strenuous activities.

One of the ways in which therapeutic ultrasound has been shown to aid in recovery of individuals is the ability of this modality to increase blood flow to a specific area of the body, increase pain relief, and increase anti-inflammatory action (Hotfiel et al., 2018). The focus of this

type of modality is on the treatment of skeletal muscle injuries and muscle damage which are an important component of the physical demands imposed daily on collegiate soccer athletes (Nédélec, 2012). Specifically, in helping with muscle damage, this type of modality reduces pain intensity among patients. Therapeutic ultrasound has also improved range of motion in knee extension and relinquish tension in myofascial trigger points of the upper trapezius (Amjad et al., 2016; Langer et al., 2017). The patients of the studies, completed by Amjad et al. in 2016 and Langer et al. in 2017, received multiple sessions of therapeutic ultrasound treatment throughout a series of weeks. This approach of providing therapeutic ultrasound incorporated with different recovery exercises for the patient's ailment fostered improved range of motion and reduced inflammation for the participating patients (Amjad et al., 2016; Langer et al., 2017). Through the reduction of inflammation and increased range of motion for these patients, this modality of recovery can also be utilized on other areas of the body with a specific time frame for the individual's recovery needs.

Another way therapeutic ultrasound can be very beneficial for athletes is its influence on post-exercise blood lactate and the following muscle performance of the individual (Langer et al., 2017). During high intensity performances of anaerobic exercises lactate is formed due to lack of oxygen to convert the pyruvate into acetyl-CoA (McArdle et al., 2015). This causes an increase in hydrogen ions in the muscles which decreases muscle pH which subsequently inhibits enzyme functions as well as slows ATP production (Langer et al., 2017; McArdle et al., 2015). Langer et al. (2017) discovered that ultrasound can be utilized to lower lactate concentration in the blood as well as improve peak torque, average power, and total work of lower body muscle performance when applied to areas of the quadriceps and hamstrings (Langer et al., 2017). This may be very beneficial for collegiate soccer athletes who endure very strenuous practices and

must clear lactate effectively and efficiently between training sessions. Therapeutic ultrasound may promote glycolytic enzyme function of the body and help reduce blood lactate concentrations leading to more pyruvate being converted into ATP for energy for the athlete (Langer et al., 2017; McArdle et al., 2015). Therapeutic ultrasound has been associated with increasing blood flow throughout the body allowing the muscles of the body to perform for much longer periods of time as well as to recover much quicker after intense exercises (Draper, 2018). This can be applied to multi-day trainings to prevent delayed fatigue of athletes as well as to maintain peak muscle performance for sustained periods of time (Draper, 2018).

One of the most interesting benefits from the use of therapeutic ultrasound is the activation of extracellular signals related to kinase signaling pathways as well as the upregulation of Beta1 integrins which causes cell proliferation (Jiang et al., 2019). These pathways control cell function in relation to increasing in number, decreasing in number, and dying. The pathways are also utilized in expressing proteins and producing changes in the cell, such as during cell division (Jiang et al., 2019). This can also include an increase in myoblast cell activity to boost overall muscle cell proliferation (Hotfiel et al., 2018). Research conducted by Jiang et al. in 2019 also established the importance of therapeutic ultrasound as a low-intensity modality with minimal thermal effects that can provide soothing stimulation to the surface of the tissue as well as the deeper layers of bodily tissues. With new research on the effects of therapeutic ultrasound, it is important to not disregard the unique and practical applications for which this modality can be utilized. Therapeutic ultrasound does not have to include these very complex signaling pathways and may be utilized in a clinical setting, as described in the previously mentioned studies conducted by Amjad et al. (2016), Hotfiel et al. (2018), and Langer et al. (2017).

In a physical therapy clinic therapeutic ultrasound is utilized on individuals that may have recently undergone surgery (Jiang et al., 2019). Common bodily fractures that have utilized therapeutic ultrasound include fractures of the tibial shaft, clavicle shaft, and radius (Palanisamy et al., 2021). These deep bone fractures in conjunction with therapeutic ultrasound can lead to healing of the fracture along with increased blood flow around the injured area (Palanisamy et al., 2021). The modality of ultrasound helps to accelerate bone formation and improve cell proliferation of new blood vessels (Palanisamy et al., 2021). This phase is termed angiogenesis and therapeutic ultrasound has been shown to help in the proliferation of these cells to achieve the structure of recovery bone. As described earlier, therapeutic ultrasound aids in signaling pathways and may help to express certain enzymes and aid in extracellular signal-regulated kinase signaling pathway which is involved in bone formation (Palanisamy et al., 2021). This therapeutic modality of ultrasound can be utilized at different stages of the fracture recovery process including fresh fractures, and delayed fractures (Palanisamy et al., 2021). From a clinical standpoint certain common fractures of the clavicle and ankles in soccer can also be applied to collegiate soccer athletes who may have injured themselves during competition. Therapeutic ultrasound may be applied on the individual to promote increased bone fracture healing to return the individual to play as safely and as methodically as possible.

Another instance of improved recovery while utilizing therapeutic ultrasound includes a study on young athletes with spondylolysis, which is a stress or fracture between the vertebrae of the spine (Tsukada et al., 2019). These young athletes were enrolled in a study to determine the effects of therapeutic ultrasound on spondylolysis and the ability of the athletes to return to play (Tsukada et al., 2019). Tsukada and researchers (2019) found that therapeutic ultrasound led to a shorter amount of time to return to play for the athletes and can be a viable source in allowing

children to recover from different injuries (Tsukada et al., 2019). Therapeutic ultrasound can aid in recovery of musculoskeletal performance of individuals and help improve physiological impairments associated with high endurance sports like collegiate soccer.

Therapeutic ultrasound also greatly aids individuals with knee osteoarthritis (Devrimsel et al., 2019). Some common symptoms of the disease include stiffness of joints, decreased range of motion, joint pain, and weakness of muscles (Devrimsel et al., 2019). Therapeutic ultrasound has been applied to patients with this type of disease which reduced individuals' symptoms. While this is more common in older adult populations there are similar symptoms between individuals with knee osteoarthritis and collegiate soccer athletes (Devrimsel et al., 2019; Nédélec, 2012). The collegiate soccer athletes with joint stiffness, weakness, fatigue, and joint pain may benefit from multiple sessions of therapeutic ultrasound to combat these symptoms. More research needs to be conducted on this treatment of knee osteoarthritis, but it does include some symptoms that can be applicable to collegiate soccer athletes in the journey of day-to-day recovery from intense training sessions and matches. This research should be conducted with a collegiate soccer team throughout the course of offseason training sessions and may provide valuable information on the potential of therapeutic ultrasound to physiologically benefit collegiate soccer players.

With the benefits of ultrasound laid out above it is very important to consider this as an important tool in optimizing the recovery of collegiate soccer players. Further research needs to be conducted on this modality in a collegiate soccer setting between Friday and Sunday matches. This future study would help provide information about whether this modality can actually aid the athletes and then be used in other sports similar to soccer that require high cardiovascular fitness and muscle endurance.

2.6: Ineffectiveness of Therapeutic Ultrasound

Despite the potential efficacy of therapeutic ultrasound some studies provide evidence that contradicts the effectiveness of therapeutic ultrasound (Aytar et al., 2008; Daniel, 2017; Desmeules et al., 2015). Aytar and colleagues' (2008) study evaluated how effective therapeutic ultrasound is in treating female university students with muscle soreness in non-dominant elbow flexors. Researchers specifically evaluated the acute myogenic condition of muscular discomfort and pain associated with the completion of strenuous exercise (Aytar et al., 2008). This study included one-hundred and twelve female university students from Baskent University, divided into three groups; ultrasound, placebo, and control (Aytar et al., 2008). The eccentric exercise machine utilized to cause the delayed onset muscle soreness was a Cybex 770 isokinetic dynamometer. After the participants completed the eccentric exercise, the participants indicated increased levels of muscle soreness. Therapeutic ultrasound was applied forty hours after exercises on the distal area of biceps brachii muscle on the affected arm. Aytar et al. (2008) concluded there was no evidence that therapeutic ultrasound was significantly superior compared to a placebo for reducing muscle soreness. Aytar et al. (2008) also concluded that there were no significant increases in muscular strength or range of motion for the patients among groups (ultrasound, placebo, and control). Delayed onset muscle soreness in this study did not significantly improve more rapidly using therapeutic ultrasound on these participants and in fact persisted 120 hours post-exercise (Aytar et al., 2008).

Figure 1: Cybex 770 isokinetic dynamometer
cybex 770 isokinetic dynamometer for elbow - Bing images

However, some issues are presented in Aytar et al.'s (2008) findings that may hinder the validity of the study's results. At the end of the discussion, they state that these findings should not be viewed as evidence that therapeutic ultrasound will not have any effect on delayed onset muscle soreness for individuals (Aytar et al., 2008). Just because this study drew this type of conclusion does not mean this is the only outcome any patient will receive when they are exposed to therapeutic ultrasound. Multiple factors can influence the outcome of the experiment and more research needs to be conducted on this issue to achieve a better understanding of the effects that therapeutic ultrasound can have on delayed onset muscle soreness (Aytar et al., 2008). This is very important to consider when attempting to answer the question "what can therapeutic ultrasound do for the human body?" Aytar et al. (2008) drew a specific conclusion but also admitted that the researchers do not possess the full scope of the issue. As with many research studies, the results outline future research that should be conducted to continue filling the gaps in what is known about the physiological impacts of therapeutic ultrasound. Future research on this topic should include effects of therapeutic ultrasound on soreness, range of motion, and muscle strength with different populations and in different settings. Aytar et al. (2008) only focused on female college students, and it will be beneficial to uncover the effects on male students and collegiate athletes. Along with elbow flexors there have been other joints, like the shoulder, that have been tested in congruence with therapeutic ultrasound (Desmeules et al., 2015).

A meta-analysis by Desmeules et al. (2015) gathered eleven sources of evidence on the discovered effects of therapeutic ultrasound specifically on rotator cuff tendinopathy to provide a comprehensive review of the findings through 2014. Rotator cuff tendinopathy is a very broad clinical term used to diagnose partial tears of the rotator cuff, pain during shoulder elevation,

decreased range of motion, and irritation and inflammation of the tendons or muscles that compose the shoulder joint (Desmeules et al., 2015). Desmeules et al. (2015) discovered that from the eleven studies that were analyzed there was not sufficient evidence that therapeutic ultrasound was superior to a placebo or another form of recovery for rotator cuff tendinopathy – specific to range of motion and level of inflammation. Overall, Desmeules et al. (2015) concluded that the present studies do not support the use of therapeutic ultrasound alone on a patient or as a part of a patient's plan of recovery. Instead, therapeutic ultrasound represented an unnecessary form of recovery.

However, some issues in the findings of this article may hinder the validity of the results. One of the limiting factors in this study was the low quality of rotator cuff tendinopathy studies. There were variations in outcome measures resulting in the use of only eleven sources specific to the use of therapeutic ultrasound for rotator cuff tendinopathy. There may have been some broad range of study bias for the research which may have contributed to choosing only a select few sources for consideration. This can lead to a skewed representation of the physiological effects associated with therapeutic ultrasound. Desmeules et al. (2015) also stated that even with their conclusions, it is impossible to definitively state the invalidity of therapeutic ultrasound in aiding individuals with physiological ailments. This article does not represent the entirety of therapeutic ultrasound and the effects that it possesses. Even though Desmeules et al. (2015) found reviews and studies that display the low quality of evidence for the use of therapeutic ultrasound, there still needs to be continued research on the effects of therapeutic ultrasound on individuals. A more refined analysis may include more equitable outcome measures of other studies and comparisons of these more equitable sources with the results of the original eleven sources of evidence.

Instead of therapeutic ultrasound being utilized alone, some researchers have opted for studies viewing the effects of therapeutic ultrasound in congruence with other modes of recovery. For example, Daniel (2017) inspected fifty individuals suffering from high ankle sprains. Daniel (2017) also evaluated the effects of proprioceptive neuromuscular facilitation (PNF). PNF is a training and stretching method utilized to increase range of motion. This occurs from the stretch by causing a shortening contraction of the opposing muscle to place the target muscle in a stretch, followed by an isometric or static stretch of the muscle, implemented to increase range of motion and flexibility (Daniel, 2017). Daniel (2017) evaluated which mode of recovery ultrasound, ultrasound with athletic ankle taping, PNF training, or PNF training with athletic ankle taping - would be the most beneficial in facilitating the healing of high ankle sprains in fifty subjects. Athletic ankle taping utilizes athletic tape to increase ankle stability and ease pain symptoms of those suffering for only about 40 minutes. The fifty subjects in this study were described only as "suffering from a high ankle sprain injury" (Daniel, 2017). These individuals were divided into five groups with ten participants in each group. The groups were broken into the provided categories above with an additional control group. The results of the study found that all the modes of recovery were helpful in reducing swelling of the ankle sprains (Daniel, 2017). However, there was no significant difference among the different modalities utilized so the researchers were unable to determine which form of recovery was the most beneficial for high

TABLE 3: SCHEFFE'S *POST HOC* ANALYSIS FOR THE DIFFERENCE BETWEEN THE ADJUSTED POSTTEST PAIRED MEANS IN THE SWELLING OF HIGH ANKLE SPRAIN INJURY OF SELECTED GROUPS

Adjusted posttest means					MEAN DIFF	CI
UT group	UT&T group	PNFT group	PNFT&T group	Control group		
64.09	63.69				0.4	0.84
64.09		63.88			0.21	0.84
64.09			64.05		0.04	0.84
64.09				64.93	0.84*	0.84
	63.69	63.88			0.19	0.84
	63.69		64.05		0.36	0.84
	63.69			64.93	1.24*	0.84
		63.88	64.05		0.17	0.84
		63.88		64.93	1.05*	0.84
			64.05	64.93	0.88*	0.84

*Significant at 0.05 level

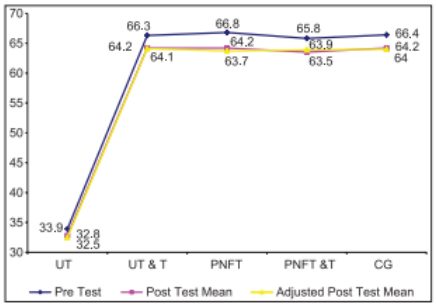

Figure 1: Line graph showing pre, post and adjusted means on high ankle sprain injury swelling

Figure 2: Mean in swelling of ankle sprain of the different subject groups (Daniel, 2017).

ankle sprains which are common in sports with high amounts of jumping and cutting which includes collegiate soccer settings. In conclusion, Daniel (2017) found that more research needs to be done concerning ultrasound, PNF, and athletic taping as modes of recovery.

However, some issues in the findings may hinder the validity of the study's results. One variable that is important to know is the age and gender of the participants in the study. No general information was provided on the participants' physiological fitness or severity of injury. These individuals might all be different ages or from very similar age ranges. This may have accounted for the results, and it would be more useful to include the ages and demographics of the studied population. This was also a very small sample with only ten individuals treated with each modality. This may not be the most inclusive or holistic representation of the effects of therapeutic ultrasound on a very important and common injury to athletes. This study also could have benefitted from also evaluating the physiological effects of therapeutic ultrasound with a control group. The information gained from this could then be utilized to compare use of ultrasound to more modalities of recovery.

Chapter 3: Future Directions

Based on the current available research there is a gap in knowledge and therefore a need to study the physiological effects of therapeutic ultrasound specific to recovery strategies for collegiate soccer players. Based on the findings in this literature review, more research is warranted to allow more experienced personnel to understand best practices for recovery and the benefits of therapeutic ultrasound as a preventative and recovery strategy in men's collegiate soccer. Speed and strength are important variables in collegiate soccer which are improved and optimized through proper recovery. With increased blood flow, decreased inflammation, and improved skeletal muscle repair collegiate soccer players can optimally recovery, improving overall strength, speed, and ability to perform at more optimal levels (Lintonbon, 2016). In conjunction with this, evidence suggests that the use of therapeutic ultrasound can increase blood flow, decrease inflammation, decrease muscle damage, and increase relaxation of muscles through internal heating effects (Lintonbon, 2016).

To optimize the recovery of collegiate soccer athletes and promote the aforementioned benefits of therapeutic ultrasound, this modality can be utilized between Friday and Sunday matches. The information gained from a research study utilizing therapeutic ultrasound in a collegiate soccer setting can lead to consistency among coaches and athletic trainers to make more informed and evidence-based practices for collegiate soccer players. Procedures to follow to optimize recovery include an introduction of therapeutic ultrasound in collegiate soccer at 1-3 MHz, a treatment time of 5-20 minutes, and application to the specific area of the body where there is inflammation or muscle soreness in between training sessions and match play (Jiang et al., 2019). For collegiate soccer athlete's, therapeutic ultrasound would be applied to the quadriceps, hamstrings, and calves because they are commonly used throughout a match

Therapeutic ultrasound can optimize recovery by reducing muscle soreness, improving range of motion, and decreasing skeletal muscle inflammation (Lintonbon, 2016).

Overall, knowledge about the use of therapeutic ultrasound specific to collegiate soccer players' recovery processes is missing from the literature and by filling this gap more information will be provided, and more evidence will be available to coaches and trainers on innovative ways to optimize recovery for collegiate athletes. The information that will be collected will include subjective and objective data on the recovery process of the athletes. A research study of the effects of therapeutic ultrasound on the recovery of collegiate soccer athletes will provide these data. Due to the current knowledge gap, implementing an interventional or experimental study with therapeutic ultrasound including a control and experimental group on a collegiate soccer team will help provide more information to make decisions about whether or not therapeutic ultrasound will be beneficial for collegiate soccer athletes in between matches. A research study will not only provide information for coaches and trainers, but also to athletes who may be struggling with physiological stressors.

An example of a proposed study that I would conduct could be based on Waters et al.'s (2021) study that analyzed the effects of therapeutic ultrasound on individuals with no health-related concerns. The control group did not receive any form of therapeutic ultrasound to improve recovery at the end of the day. The experimental groups underwent a session of therapeutic ultrasound following the completion of a normal day in their life (Waters et al., 2021). Waters et al. (2021) employed a procedure for each session that included a 10-minute continuous wave-length session, at a 1MHz frequency, encompassing the entire area of pain or concern, and in a reclined and stationary position. A 1 MHz frequency is the most commonly used frequency in recovery settings which is why I will implement this frequency in my research

study (Jiang et al., 2019).Waters et al. (2021) evaluated the effects of therapeutic ultrasound and found that the aforementioned procedure increased blood flow for the participants. Furthermore, a study conducted by Daniel (2017) may also be beneficial to examine due to the procedure of measuring inflammation and swelling following a treatment of ultrasound. Daniel (2017) utilized a measuring tape to measure inflammation and swelling and I may utilize this in my research project as well as a goniometer to measure range of motion of different joints of the body. By utilizing Waters et al. (2021) and Daniel's (2017) data collection methods, my proposed research study can evaluate the effects of therapeutic ultrasound on inflammation and overall recovery of an experimental group as compared to a control group of collegiate soccer players. Utilizing the aforementioned procedures and conducting a close proximal study of my own may lead to a convenient and beneficial research study. I am a current undergraduate biology student and a future Doctor of Physical Therapy student. The Regis University Doctor of Physical Therapy Program requires students within the three years of the program to complete a research study. This would be a convenient research proposal for myself as I could sample the Regis University men's soccer team.

The purpose of my research study is to uncover the physiological effects that therapeutic ultrasound possesses when utilized in a collegiate soccer recovery setting in between matches. My research question is whether or not men's collegiate soccer athletes experience improvements in recovery process in between games. These improvements in recovery processes can focus on objective measurements of speed and sprint distances while also viewing subjective feelings of muscle soreness and rate of perceived exertion (RPE). I will take objective measurements through the use of PlayerTek or Metrifit technologies which are monitoring software in the form of a GPS tracker or vest that can measure variables such as sprint distance,

total distance covered, and top speed. I will also take subjective measurements through the use of wellness questionnaires as well as Metrifit which allows athletes to complete questions about their overall well-being and provide responses to different training sessions. Another variable that I may be evaluate is muscle strength and how therapeutic ultrasound may mitigate muscle damage following a match. This will provide additional evidence and information to make more informed decisions about the recovery process for collegiate soccer athletes.

As stated previously the variables that I will be explore in this proposed research study are objective measurements of speed and sprint distances along with subjective measurements of collegiate soccer athlete's RPE and muscle soreness following match-play. Some of the limitations that may arise from these scenarios include proper use of the technology and GPS trackers so that proper objective data are taken. All subjective data must be collected using the same questions and conducted at the same time following a match. Some limitations of subjective data collection include data collected from the athletes that may not be completely truthful in their self-reporting as to not affect their playing time. The most important practice to address these limitations is to have a consistent procedure that considers the athletes as the number one priority. This will help to make sure that therapeutic ultrasound is utilized to optimize the recovery of these athletes and help improve their match day performances.

My research study would include the permission of Regis University Athletics and members of the Regis University Men's Soccer Team to approve and participate in this study. IRB approval will be attained from each of the participating review board members before beginning this research project. Funding will also need to be procured to purchase a therapeutic ultrasound machine and for necessary supplies such as Myogel. Prices vary widely for therapeutic ultrasound machines with many as low as $200. However, for my research project a

suitable machine will be around $2,000 and the Myogel that will be utilized costs about $25 for a 5 Liter container. For a twenty-two athlete roster a membership for PlayerTek will cost $3410 per year.

After informed consent is achieved from all of the participants it is important to divide the study groups into control and experimental groups. After Friday and Sunday matches the experimental group would receive therapeutic ultrasound to view post-treatment objective data of range of motion utilizing a goniometer, and skeletal muscle inflammation through the use of circumference measurements. The ultrasound treatment sessions will be administered by a physical therapist for the men's collegiate soccer team. The control group will not receive therapeutic ultrasound, but both the experimental and control groups will complete subjective wellness questionnaires. Qualitative data will evaluate post-match muscle soreness through the use of wellness questionnaires that ask where the muscles soreness is as well as overall rate of perceived exertion (RPE) of the athlete. RPE is a scale used to identify how intense or hard an individual is exercising. I will collect these data within three hours upon completion of match play so that athletes possess enough time to receive treatment and fill out the questionnaires. My research study will last for 14 weeks throughout the entirety of the Regis University men's soccer team fall season. It may be beneficial to focus on a specific muscles throughout this time such as the quadriceps, hamstrings, and calves based on high use of these lower body muscles in collegiate soccer. RPE would be recorded for every individual following the completion of both Friday and Sunday matches as well as utilizing Metrifit data to view perceived levels of muscle soreness and fatigue pre- and post-therapeutic ultrasound treatment from both Friday and Sunday matches.

The findings of this study will lead to follow up studies of the proper use, timeframe, and application of therapeutic ultrasound to optimize the recovery of collegiate soccer athletes. As stated previously, strength may be another variable that can be evaluated for collegiate soccer athletes and their recovery. Following the completion of my research study steps will be taken to decide if therapeutic ultrasound may be utilized during offseason training sessions, preparing for regular season competition.

Chapter 4: Conclusion

Men's collegiate soccer is a very physiologically demanding sport that requires athletes to be physically optimized to perform at the highest level. This sport demands that athletes be aerobically fit, anaerobically fit, and possess high muscular endurance (Nédélec, 2012). Along with these needs, collegiate soccer comes with physical stressors that can be mitigated through evidence-based findings about the use of therapeutic ultrasound (Kupperman et al., 2021). The recovery of collegiate soccer players from these evidence-based findings can be improved because therapeutic ultrasound includes aspects that sustain range of motion, repair muscle microtrauma caused in collegiate soccer games, decrease inflammation, and decrease levels of muscle pain like muscle soreness. Since collegiate soccer athletes experience skeletal muscle damage, skeletal muscle soreness, and a heightened sympathetic nervous systems this tool may be very useful in aiding in the need for rapid recovery of collegiate soccer athletes. This machine can be beneficial for collegiate soccer athletes because of the utilization of sound waves at different frequencies to penetrate the tissues of the skin and alleviate the aforementioned issues following match play (Lintonbon, 2016).

To optimize the performance of an athlete it is important to explore different recovery strategies in conjunction with strategies like nutrition, hydration, and sleep. Therapeutic ultrasound addresses the physiological effects of soccer matches such as inflammation, soreness, and decreased range of motion (Lintonbon, 2016). However, therapeutic ultrasound has not been studied in a collegiate soccer setting and currently application of therapeutic ultrasound is speculative due to this lack of research. Based on the gap in knowledge for therapeutic ultrasound in collegiate soccer settings it is difficult to determine what the true effects of this modality will be on the recovery of collegiate soccer athletes and the resulting performances. It is

also important to note that some studies have provided evidence that contradict the effectiveness of therapeutic ultrasound (Aytar et al., 2008; Daniel, 2017; Desmeules et al., 2015).

However, most research demonstrates some of the physiological benefits of ultrasound such as decreased inflammation, decreased soreness, and increased range of motion (Lintonbon, 2016). The aforementioned issues arise for collegiate soccer players following match play if not dealt with properly (Nédélec, 2012). Because of the issues that therapeutic ultrasound addresses for collegiate soccer athletes it is worthwhile to explore the possibility that therapeutic ultrasound may result in optimized recovery and increased performance of these athletes. The results of my proposed research study may allow men's collegiate soccer athletes to experience improvements in recovery processes in between games when therapeutic ultrasound is administered. Therapeutic ultrasound utilized in congruence with a holistic, and well-rounded recovery plan will include proper nutrition, adequate sleep, and promotion of healthy athletes. By gaining more information through the process of literature review and supplemental data collection health professionals, coaches, and athletes will be better informed about the physiological benefits that therapeutic ultrasound possesses for the optimization of recovery.

This optimization of recovery is not limited to the sport of collegiate soccer. If the results of my research study display therapeutic ultrasound as optimizing recovery and improving athlete performance, it will be worthwhile to apply these findings to other athletes. This will lead to applications across other endurance and power sports such football, basketball, volleyball, cross country, and lacrosse. It will also be worthwhile to uncover more information on how therapeutic ultrasound will affect the recovery of female athletes. Through continued research and application therapeutic ultrasound can be applied in many clinical settings to aid in athletic performance and recovery.

References

Amjad, F., Shahid, H. A., Batool, S., Ahmad, A., & Ahmed, I. (2016). A Comparison on Efficacy of Transcutaneous Electrical Nerve Stimulation and Therapeutic Ultrasound in Treatment of Myofascial Trigger Points. *Khyber Medical University Journal*, *8*(1), 3–6.

Anderson, T., Adams, W. M., Martin, K. J., & Wideman, L. (2021). Examining Internal and External Physical Workloads Between Training and Competitive Matches Within Collegiate Division I Men's Soccer. *Journal of Strength and Conditioning Research*. https://doi-org.dml.regis.edu/10.1519/JSC.0000000000004149

Aytar, A., Tüzün, E. H., Eker, L., Yürük, Z. Ö. B., Daşkapan, A., & Akman, M. N. (2008). Effectiveness of low-dose pulsed ultrasound for treatment of delayed-onset muscle soreness: A double-blind randomized controlled trial. *Isokinetics & Exercise Science*, *16*(4), 239–247.

Bachu, V. S., Kedda, J., Suk, I., Green, J. J., & Tyler, B. (2021). High-Intensity Focused Ultrasound: A Review of Mechanisms and Clinical Applications. *Annals of Biomedical Engineering: The Journal of the Biomedical Engineering Society*, 1. https://doi.org/10.1007/s10439-021-02833-9

Birditt, K. S., Tighe, L. A., Nevitt, M. R., & Zarit, S. H. (2018). Daily Social Interactions and the Biological Stress Response: Are There Age Differences in Links Between Social Interactions and Alpha-Amylase? *Gerontologist*, *58*(6), 1114–1125. https://doi-org.dml.regis.edu/10.1093/geront/gnx168

Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., & Thomas, K. (2017). Etiology and Recovery of Neuromuscular Fatigue following Competitive Soccer Match-Play. *Frontiers in Physiology*, 1–14.

Cross, K. M., Saliba, S. A., Conaway, M., Gurka, K. K., & Hertel, J. (2015). Days to Return to Participation After a Hamstrings Strain Among American Collegiate Soccer Players. *Journal of Athletic Training (Allen Press)*, *50*(7), 733–741.

Daniel, C. D. L. (2017). Effects of ultrasound therapy with taping PNF training and PNF training with taping in treatment and rehabilitation of sports injuries of high ankle sprain. *Journal of Dr. NTR University of Health Sciences*, *6*(2), 92–97. https://doi.org/10.4103/2277-8632.208003

Desmeules, F., Boudreault, J., Roy, J.-S., Dionne, C., Frémont, P., & MacDermid, J. C. (2015). The efficacy of therapeutic ultrasound for rotator cuff tendinopathy: A systematic review and meta-analysis. *Physical Therapy in Sport*, *16*(3), 276–284. https://doi.org/10.1016/j.ptsp.2014.09.004

Devrimsel, G., Metin, Y., & Serdaroglu Beyazal, M. (2019). Short-term effects of neuromuscular electrical stimulation and ultrasound therapies on muscle architecture and functional capacity in knee osteoarthritis: a randomized study. *Clinical Rehabilitation*, *33*(3), 418–427.

Draper, D. O. (2018). Accelerated Recovery Through Ultrasound Therapy: Lactic Acid Clearance and Muscle Recovery. Glob J Ortho Res. 1(2): GJOR.MS.ID.000509.

Gómez-Carmona, C. D., Bastida-Castillo, A., Ibáñez, S. J., & Pino-Ortega, J. (2020). Accelerometry as a method for external workload monitoring in invasion team sports. A systematic review. *PLoS ONE, 15*(8), 1–25. https://doi.org/10.1371/journal.pone.0236643

Haff, G. and Dumke, L. (2012). Laboratory Manual for Exercise Physiology. *Human Kinetics*. Champain, IL.

Hammond, L. , Lilley, J. , Ribbans, W. & (2013). Defining Recovery. *Clinical Journal of Sport Medicine, 23* (3), 157-159. doi: 10.1097/JSM.0b013e3182856329.

Hainline, B., Derman, W., Vernec, A., Budgett, R., Deie, M., Dvořák, J., Harle, C., Herring, S. A., McNamee, M., Meeuwisse, W., Lorimer Moseley, G., Omololu, B., Orchard, J., Pipe, A., Pluim, B. M., Ræder, J., Siebert, C., Stewart, M., Stuart, M., Turner, J., Ware, M., Zideman, D., Engebretsen, L. (2017). International Olympic Committee consensus statement on pain management in elite athletes. *British Journal of Sports Medicine*, *51*(17), 1245–1258. https://doi.org/10.1136/bjsports-2017-097884

Hotfiel, T., Seil, R., Bily, W., Bloch, W., Gokeler, A., Krifter, R. M., Mayer, F., Ueblacker, P., Weisskopf, L., & Engelhardt, M. (2018). Nonoperative treatment of muscle injuries - recommendations from the GOTS expert meeting. *Journal of Experimental Orthopaedics*, *5*(1), 1.

Jenne, J. W., Preusser, T., & Günther, M. (2012). High-intensity focused ultrasound: Principles, therapy guidance, simulations and applications. *Zeitschrift Für Medizinische Physik*, *22*(4), 311–322. https://doi.org/10.1016/j.zemedi.2012.07.001

Jiang, X., Savchenko, O., Li, Y., Qi, S., Yang, T., Zhang, W., & Chen, J. (2019). A Review of Low-Intensity Pulsed Ultrasound for Therapeutic Applications. *IEEE Transactions on Biomedical Engineering, Biomedical Engineering, IEEE Transactions on, IEEE Trans. Biomed. Eng*, *66*(10), 2704–2718. https://doi.org/10.1109/TBME.2018.2889669

Kopec, T. J., Hibberd, E. E., Roos, K. G., Djoko, A., Dompier, T. P., & Kerr, Z. Y. (2017). The Epidemiology of Deltoid Ligament Sprains in 25 National Collegiate Athletic Association Sports, 2009-2010 Through 2014-2015 Academic Years. *Journal of Athletic Training (Allen Press)*, *52*(4), 350–359.

Kupperman, N., DeJong, A. F., Alston, P., Hertel, J., & Saliba, S. A. (2021). Athlete Workloads During Collegiate Women's Soccer Practice: Implications for Return to Play. *Journal of Athletic Training (Allen Press)*, *56*(3), 321–330.

Lamond, L. C., Caccese, J. B., Buckley, T. A., Glutting, J., & Kaminski, T. W. (2018). Linear Acceleration in Direct Head Contact Across Impact Type, Player Position, and Playing Scenario in Collegiate Women's Soccer Players. *Journal of Athletic Training (Allen Press)*, *53*(2), 115–121.

Langer, M. D., Byrne, H. K., Henry, T., Lewis, G., & Mattern, C. (2017). The Effect of Low Intensity Wearable Ultrasound on Blood Lactate and Muscle Performance after High Intensity Resistance Exercise. *Journal of Exercise Physiology Online*, *20*(4), 132–146.

Lintonbon, D. (2016). What is Therapeutic Ultrasound? *Podiatry Review*, *73*(2), 8–9.

Lotfi, M., Azizi, M., Tahmasebi, W., & Bashiri, P. (2020). Efficacy of Beetroot Juice Consumption on the Lipid Profile of Female Soccer Players. *Medical Laboratory Journal*, *14*(2), 26–30. https://doi.org/10.29252/mlj.14.2.26

Mansfield, C. J., Beaumont, J., Tarnay, L., & Silvers, H. (2013). Popliteus Strain with Concurrent Deltoid Ligament Sprain in an Elite Soccer Athlete: A Case Report. *International Journal of Sports Physical Therapy*, *8*(4), 452–461.

McArdle, W.D., Katch, F.I., and Katch, V.L. (2015). Exercise Physiology; Energy, Nutrition and Human Performance (8th ed.). Lippincott, Williams and Wilkins.

McCollum, G., Bekerom, M., Kerkhoffs, G., Calder, J., & Dijk, C. (2013). Syndesmosis and deltoid ligament injuries in the athlete. *Knee Surgery, Sports Traumatology, Arthroscopy*, *21*(6), 1328–1337.

Morishita, K., Karasuno, H., Yokoi, Y., Morozumi, K., Ogihara, H., Ito, T., Fujiwara, T., Fujimoto, T., & Abe, K. (2014). Effects of Therapeutic Ultrasound on Intramuscular Blood Circulation and Oxygen Dynamics. *Journal of the Japanese Physical Therapy Association*, *17*(1), 1–7.

Moseley, G. L., Baranoff, J., Rio, E., Stewart, M., Derman, W., & Hainline, B. (2018). Nonpharmacological Management of Persistent Pain in Elite Athletes: Rationale and Recommendations. *Clinical Journal of Sport Medicine*, *28*(5), 472–479.

Moya-Amaya, H., Molina-López, A., Berralaguilar, A. J., Rojano-Ortega, D., La Rosa, C. J. B.-D., & La Rosa, F. J. B.-D. (2021). Bioelectrical Phase Angle, Muscle Damage Markers and Inflammatory Response After a Competitive Match in Professional Soccer Players. *Polish Journal of Sport & Tourism*, *28*(3), 8–13.

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2012). Recovery in Soccer: Part I — Post-Match Fatigue and Time Course of Recovery. *Sports Medicine*, *42*(12), 997. https://doi-org.dml.regis.edu/10.1007/bf03262308

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2013). Recovery in Soccer: Part II—Recovery Strategies. *Sports Medicine*, *43*(1), 9. https://doi.org/10.1007/s40279-012-0002-0

Page, M. J., Green, S., Mrocki, M. A., Surace, S. J., Deitch, J., McBain, B., Lyttle, N., & Buchbinder, R. (2016). Electrotherapy modalities for rotator cuff disease. *The Cochrane Database of Systematic Reviews*, *6*, CD012225. https://doi.org/10.1002/14651858.CD012225

Palanisamy, P., Alam, M., Li, S., Chow, S. K. H., & Zheng, Y.-P. (2021). Low-Intensity Pulsed Ultrasound Stimulation for Bone Fractures Healing: A Review. *Journal of Ultrasound in Medicine : Official Journal of the American Institute of Ultrasound in Medicine*. https://doi.org/10.1002/jum.15738

Silva, J. R., Rumpf, M. C., Hertzog, M., Castagna, C., Farooq, A., Girard, O., & Hader, K. (2018). Acute and Residual Soccer Match-Related Fatigue: A Systematic Review and Meta-analysis. *Sports Medicine*, *48*(3), 539. https://doi.org/10.1007/s40279-017-0798-8

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. *Dialogues in clinical neuroscience*, *8*(4), 383–395. https://doi.org/10.31887/DCNS.2006.8.4/ssmith

Stenqvist, T. B., Melin, A. K., Garthe, I., Slater, G., Paulsen, G., Iraki, J., Areta, J., & Torstveit, M. K. (2021). Prevalence of Surrogate Markers of Relative Energy Deficiency in Male Norwegian Olympic-Level Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, *31*(6), 497–506.

Tsukada, M., Takiuchi, T., & Watanabe, K. (2019). Low-Intensity Pulsed Ultrasound for Early-Stage Lumbar Spondylolysis in Young Athletes. *Clinical Journal of Sport Medicine*, *29*(4), 262–266.

Waters, M., Miljkovic, B., Rascon, J., Gomez, M., & Gurovich, A. N. (2021). Effects of 1 MHz Therapeutic Ultrasound on Limb Blood Flow and Microvascular Reactivity: A Randomized Pilot Trial. *International Journal of Environmental Research & Public Health*, *18*(21), 11444.

Yang, Q., Gayani K. Nanayakkara, Charles Drummer, Yu Sun, Candice Johnson, Ramon Cueto, Hangfei Fu, Ying Shao, Luqiao Wang, William Y. Yang, Peng Tang, Li-Wen Liu, Shuping Ge, Xiao-Dong Zhou, Mohsin Khan, Hong Wang, & Xiaofeng Yang. (2017). Low-Intensity Ultrasound-Induced Anti-inflammatory Effects Are Mediated by Several New Mechanisms Including Gene Induction, Immunosuppressor Cell Promotion, and Enhancement of Exosome Biogenesis and Docking. *Frontiers in Physiology*, *8*. https://doi.org/10.3389/fphys.2017.00818

Yim, E. S., & Corrado, G. (2012). Ultrasound in Athletes: Emerging Techniques in Point-of-Care Practice. *Current Sports Medicine Reports*, *11*(6), 298–303.

Yli-Piipari, S. (2019). Energy Expenditure and Dietary Intake of Female Collegiate Tennis and Soccer Players during a Competitive Season. *Kinesiology*, *51*(1), 70–77.