Review

Exertional Compartment Syndrome and the Development of Preventative Measures

Meaghan Mulvey *

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Review

Exertional Compartment Syndrome and the Development of Preventative Measures

Meaghan Mulvey

memulvey@som.geisinger.edu

Abstract: Throughout this paper the effects of injuries on athletes are highlighted in different aspects. Exertional compartment syndrome is a specific injury related to athletes that is thoroughly explored in this paper through an analysis of the anatomy, symptoms, diagnosis and treatments of the syndrome. Exertional compartment syndrome is an exercise-induced muscle and nerve condition that causes pain, swelling as well as disability in the affected muscles of the lower leg. This syndrome commonly develops in young athletes involved in sports with excessive running and repetitive impact such as track and field, soccer, basketball and lacrosse. Exertional compartment syndrome is commonly misdiagnosed as other less severe injuries such as shin splints, which is symptomatic of pain along the tibia bone of the lower leg caused by overuse. The misdiagnosis of exertional compartment syndrome allows the syndrome to worsen and intensify resulting in the only effective treatment to be fasciotomy, a surgical procedure to release the pressure within the compartment of the lower leg. There is no definitive protocol developed for patients after fasciotomy is performed. Athletes experiencing similar symptoms after surgery are usually treated for their symptoms rather than the syndrome as a whole, which does not have a high degree of success. The development of a definitive protocol utilizing the techniques of manual therapy, mobility stretching and corrective strength training can improve the adverse effects of exertional compartment syndrome as well as restore functionality to the athlete. Raising awareness of this syndrome in athletics will be effective in treating the athlete early on in order to avoid severe effects and invasive procedures.

Keywords: exertional compartment syndrome; compartment syndrome; sports; exercise; injury; protocol; preventative measures; diagnosis; treatment; anatomy; physiology; corrective strength training; physical therapy

Introduction

Injury is a common occurrence in everyday life among individuals. Injury is classified as any damage to the human body. Injuries occur due to an impact on the body or a penetration to the body. Individuals of all ages are susceptible to injury whether it is minor or severe. Minor injuries are not incredibly serious as they commonly require rest and/or an at home medical kit. Severe injuries frequently require medical evaluation that consists of x-rays, CAT scans, MRIs, pain medication, antibiotic treatment, stitches, splints, casts, and in even worse circumstances, surgery. Some injuries may occur due to underlying health conditions which cause an individual to stumble and suffer a fall when they did not intend to do so. This can be avoided by regular wellness visits and testing by the individual's primary physician. Although all individuals are susceptible to various injuries, athletes in particular have a greater risk due to the constant impact of stress on their bodies from physical workouts, training sessions and in certain sports, colliding with other individuals.

Injury is extremely common in athletics, however the severity of the injury is often ignored due to the demand of quality performance. This is also due to the concern of athletes that a teammate is getting ahead while they are healing. The ignorance of severe symptoms and injuries often results in the condition worsening which may limit the treatment options available. When an athlete continues to play through an injury, there are many possible negative outcomes that commonly occur. One

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potential outcome is that the minor injury will develop into a more severe injury. An athlete who experiences a minor fracture and continues to play with this injury instead of treating it has a high risk of developing a more serious and larger fracture, which can then result in surgical treatment with an extended recovery time. An injury to the brain such as a concussion, a very common injury suffered by athletes that is not treated correctly can ultimately lead to second impact syndrome[1]. This can occur if another head injury is sustained, even if it is just a slight concussion. In circumstances where the first concussion was not treated properly a more severe brain injury may develop which of course also affects everyday life outside of athletics. Another potential occurrence which may happen when an injury is not treated is that the body will begin to use other muscles to compensate for the injured muscle. This leads to overuse of the wrong muscles and the overused muscles can become damaged due to use in performing actions which they were not primarily designed to carry out. It is not unusual for an athlete to be advised to play through the pain while taking a painkiller. A study done by German researchers reviewing 15 studies on this topic of pain involving 550 athletes and 330 individuals with normal activity levels, concluded that athletes become unable to distinguish between everyday soreness and a serious condition[1]. This is because they become adapted to playing through pain, which eventually is interpreted as soreness from overuse. Unfortunately, there is not enough awareness about certain injuries due to the lack of education provided to athletes and coaches concerning rare but severe injuries.

One severe injury that is commonly overlooked is Exertional Compartment Syndrome (ECS), also known as Chronic Compartment Syndrome. As an individual exercises, specific muscle compartments swell up to 20% and normally there is compensation in the compartment for the increased blood flow and fluid volume. However, with exertional compartment syndrome there is a rise in the pressure within one or multiple musculofascial compartments, most commonly in the lower leg, preventing muscle expansion which in turn compromises blood flow to the lower leg. The volume and pressure reach a level that overrides the capillary's perfusion pressure. The buildup of pressure causes pain, motor weakness and/or paresthesias in the area associated with the compartment with the increased pressure[2]. This severe condition is usually misdiagnosed as shin splints. In some cases, the misdiagnosis has lasted for as long as two years. Shin splints are a less severe injury where the muscles, tendones and bone tissue are overworked causing pain and uncomfort along the tibia bone in the lower leg. This is dangerous as misdiagnosis can cause the symptoms of exertional compartment syndrome to intensify over time with risk of permanent damage and it also may increase recovery time. Doctors, specifically orthopedists and those dealing with the lower leg, should be thoroughly trained to recognize the signs of exertional compartment syndrome in order to be sure patients are not misdiagnosed with something less serious. A better protocol can be developed through actively researching specific factors that intensify the symptoms as well as the overall anatomy of the body, in order to minimize as much trauma as possible. An additional mitigating factor would be to require educational seminars for athletes and especially coaches to learn about the severity of common injuries that develop in specific sports in order to treat the injuries earlier, rather than later, when the condition is far more severe. Pain in athletics is not always as simple as putting ice on the area for the night and expecting it to be ready to perform the next day. There may be an issue in the underlying anatomy of the body that is not visible to the eye.

Compartment Syndrome

Compartment syndrome itself is a painful condition that occurs when pressure within the muscles rises to dangerous levels. The buildup of pressure decreases blood flow preventing nourishment and oxygen from reaching nerve and muscle cells. This condition is defined as two forms: Acute Compartment Syndrome and Chronic Compartment Syndrome. Acute Compartment Syndrome is a critical medical emergency. This syndrome is caused by a severe or traumatic injury to the affected area[3]. If this is not treated it can lead to permanent muscle and soft tissue damage. In severe cases of prolonged blocked blood flow from the traumatic injury it can lead to loss of the affected limb. To prevent serious complications induced by acute compartment syndrome it is suggested that fasciotomy should be performed in close time proximity to the traumatic injury before

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irreversible tissue necrosis occurs[4]. The fasciotomy performed is commonly described as a prophylactic fasciotomy which is an initiative to prevent serious disease. The performance of the fasciotomy procedure earlier rather than later reduces the risk of rhabdomyolysis and myonecrosis development as well as functional loss within limbs. Rhabdomyolysis is a medical condition that can result in permanent disability due to damaged muscle tissue releasing proteins and electrolytes into the blood which can damage the heart and kidneys, which can become fatal[5]. Myonecrosis is a soft tissue infection that occurs after a deep penetrating injury that compromises blood supply[6]. Acute compartment syndrome primarily occurs in the lower leg, forearm, thigh, foot, gluteal region, hand and abdomen[4].

Chronic Compartment Syndrome is also defined as Exertional Compartment Syndrome. This form of the syndrome is not characterized as a medical emergency as compared to acute compartment syndrome, however it is still serious because if untreated it can cause significant damage within the affected area. Exertional compartment syndrome's main cause is athletic exertion[3]. During exercise or athletic activity a swelling of the muscle occurs, which is normal, however with this syndrome the muscle swells more than the fascia can stretch thereby causing a buildup of pressure on the capillaries, nerves and muscles in the compartment of the affected area[3]. The buildup of pressure constricts blood flow and oxygen supply to the muscle and nerve cells causing intense pain. Exertional compartment syndrome can occur in muscle compartments of any limb in the body, however 95% of cases are seen in the compartments of the lower leg. In 82% of the cases the pain is present in both legs, with the same compartment in each leg being affected by exertional compartment syndrome[7]. This condition is most frequently seen in runners, also including sports such as soccer, field hockey, basketball and lacrosse. This condition is also seen in military members, specifically new recruits and infantry soldiers, due to lower extremity overuse injuries[8].

Anatomy and Symptoms of Exertional Compartment Syndrome

Exertional compartment syndrome can occur in either the superficial posterior compartment, deep posterior compartment, lateral compartment or the anterior compartment of the lower leg. In some cases ECS is seen in multiple compartments in the lower leg. The compartments consist of specific muscles and nerves contained within non-compliant fascial and osseous boundaries[9]. The fascia is a casing of connective tissue that surrounds blood vessels, bones, nerve fibers and muscles holding them in their respective place within the body. Osseous consists of the bone, which is part of the skeletal system. The anterior compartment is associated with specific muscles such as the anterior tibialis muscle, extensor hallucis longus muscle, extensor digitorum longus muscle and the fibularis tertius muscle. The anterior compartment is associated with the deep fibular nerve and the anterior tibial artery as well as vein. These components are affected when pressure levels in the anterior compartment rises, inhibiting prime function of each component it is associated with. The deep posterior compartment is similar to the anterior compartment as it affects muscles, nerves and vasculature. The superficial posterior compartment and the lateral compartment affect both the muscles and nerves, however they do not have an impact on vasculature. The deep posterior compartment affects the specific muscles flexor hallucis longus muscle, flexor digitorum longus muscle, posterior tibialis muscle, and the popliteus muscle. The deep posterior compartment also affects the posterior tibial nerve, the posterior tibial artery and vein and the fibular artery and vein. The superficial posterior compartment affects the gastrocnemius muscle, soleus muscle and the plantaris muscle as well as the sural nerve. The lateral compartment affects the fibularis longus muscle, the fibularis brevis muscle and the superficial fibular peroneal nerve[9]. The entirety of muscles, nerves and vasculature that each of the four compartments affect is what causes this syndrome symptoms to be so intense. The connection of the muscular system and the nervous system highlight why untreated symptoms can be quite dangerous.

The symptoms arise as exercise begins and will intensify during exercise. The time of symptom development is usually five to ten minutes after starting exercise. Symptoms of ECS are throbbing pain, tingling sensation, numbness, swelling and weakness of the affected area. In more severe cases, foot drop is also a common symptom. This is when an individual has difficulty lifting their foot up

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due to the lack of blood flow and circulation to the foot. These symptoms will subside once exercise is stopped and the individual is at rest. The most affected group of individuals are young athletes involved in high intensity running sports. There are studies that were performed comparing the results of exertional compartment syndrome present in males and females, each study had a slightly different result. In one study 1411 heterogeneous patients who had complaints of lower extremity pain had dynamic intracompartmental pressures performed. Of these 1411 patients within the study, 698 were diagnosed with exertional compartment syndrome. The outcome of this demonstrated a peak prevalence at 20 to 25 years with a higher likelihood in males than females with a bilateral presence[10]. Despite this conclusion another study suggested that in the pediatric population that females are at the highest risk of Exertional Compartment Syndrome with a peak age of 16 years old[9]. There has not been extensive research into exertional compartment syndrome, therefore these conflicting conclusions are plausible as new findings are observed in each study due to the lack of detailed knowledge about this syndrome as a whole. An interesting comparison between these studies is that the peak age is above 20 for males, but is lower for females. Another relevant study is not directly related to ECS, but primarily dealt with fascia elasticity. The study concluded that anterior cruciate ligament (ACL) injuries are associated with changes in anterior and posterior cruciate ligament laxity due to changes in body temperature during the menstrual cycle as well as the effect of beta estrogen receptors on the ligaments[11]. This study also observed plantar fascia in women and men, displaying that estrogen has the same effect on the fascia that it does on the ligaments. This can further support the study concluding the rate of ECS diagnosis is increasing in women with a peak age of 16 because as the menstruation cycle occurs, the elasticity of the fascia changes which can impact ECS as a whole. Women usually get their first period between the ages of 10 and 15, therefore at the age of 16 their menstruation cycles are beginning to become more fixed than irregular. This can contribute to the large diagnosis of ECS in young female athletes during this time period in their lives.

Diagnosis and Treatment of Exertional Compartment Syndrome

Exertional compartment syndrome is commonly misdiagnosed due to other exercise related issues which are more widely recognized. ECS is frequently misdiagnosed as shin splints which is an exertional pain along the shin bone, also known as the tibia. The symptoms of shin splints can overlap with ECS, especially aching pain in the lower leg radiating into the bottom of the foot[12]. Shin splints are detected through evaluation of the pain experienced as well as X-ray results. The X-ray will be taken of the lower leg in three different angles such as on the right of the tibia bone, to the left of the tibia bone and the front of the tibia bone. In these X-rays there will be visible small cracks on the tibia bone, occurring from overuse of the muscle and rest will be prescribed in order to subside the issue. Therefore, after evaluating the patient physicians usually conclude the diagnosis to be shin splints and they remain unaware of the presence of ECS. Exertional compartment syndrome can not be diagnosed through X-rays or through magnetic resonance imaging (MRIs). An X-ray is a technique that uses electromagnetic waves to create pictures of the inside of an individual's body. X-rays' primary function is to detect fractures in the bones. X-rays can also be used in other ways such as detection of pneumonia and breast cancer[13]. Magnetic resonance imaging is a technique that uses magnets, radio waves, and a computer to make detailed pictures of the inside of an individual's body. MRIs are often used to specifically view various soft tissues and the nervous system[14]. Exertional compartment syndrome cannot be detected by these techniques because the pressure and resulting symptoms only occur during exertion.

In order to diagnose ECS, the intracompartmental pressure test is performed by physicians who undergo specific training and certification in order to perform this test. The test is performed under the supervision of a physician and in a medical facility. Firstly, the physician will observe the individual's lower leg to detect where each compartment is, in order to correctly insert the first needle which injects numbing medication into the area of the compartment. Next, the Strkyer catheter device is inserted into each compartment at a time in order to get a pressure measurement of the individual's compartment at rest. The Strkyer catheter is a handheld needle that includes a pressure scale[15]. After

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the compartment measurements are taken at rest, the patient will undergo exertional exercise, most commonly running on a treadmill in the medical facility, until severe symptoms begin to occur. Once symptoms occur, the physician will use the Strkyer device to measure the compartment pressure levels after exertion. If the pressure of the compartment at rest is greater than 15 mmHg and the pressure five minutes post exercise is greater than 20 mmHg, a diagnosis of ECS is confirmed[15]. Additionally, the borderline levels of severe cases is 30 to 40 mmHg fives minutes post exercise, therefore if the pressure is greater than 40 mmHg the diagnosis of exertional compartment syndrome is quite severe in which case surgical intervention is ultimately recommended to alleviate the symptoms. One downside of the intracompartmental pressure test is that it does cause minimal pain and discomfort due to the insertion of needles into the compartment. The intracompartmental pressure test is the most accurate way to diagnose ECS, however another method is able to diagnose ECS through viewing the constriction of the blood vessels after exertion with an ultrasound. The intracompartmental pressure test is more accurate due to having a fixed scale of numbers, however performing an ultrasound is a painless technique that is able to visually observe what is happening within the compartment. An ultrasound is effective in visualizing the subcutaneous and soft tissue structures of the musculoskeletal system which includes the peripheral nervous system[16]. Exertional compartment syndrome is frequently misdiagnosed for up to two years because there are other more familiar and more common diagnoses for symptomatic pain in young athletes. This is dangerous because the syndrome begins to worsen when it is left untreated. However, with the correct evaluation it can be diagnosed accurately and in a timely manner so that it may be treated properly.

There are limited treatments available for exertional compartment syndrome due to the complexity of the overall anatomy. When first diagnosed with exertional compartment syndrome the first step in the treatment process is for the patient to have a conversation with their primary orthopedist and orthopedic surgeon. The common treatment for ECS is a surgical procedure known as fasciotomy that consists of the cutting of the fascia to allow for the expansion of the muscle and to relieve the constriction of blood flow. Fasciotomy provides for the relief of symptoms and the prevention of nerve damage. Surgical fasciotomy for acute compartment syndrome has been used successfully for many years. The original open 2-incision technique to treat ECS has been in use since World War II. With the advancement of science, ECS fasciotomy has evolved toward less invasive techniques. In 1956, Mavor published the first proposal for surgical treatment for exertional compartment syndrome recognizing that the treatment is different from acute compartment syndrome. In 1987, Due and Nordstrand developed a minimally invasive subcutaneous, applied under the skin fasciotomy. This was performed by using several small incisions to blindly divide the fascia[17]. In the years since then, significant advancements have been made to develop endoscopic techniques that require miniscule incisions. Endoscopic surgeries utilize specialized instruments to view as well as operate on the fascia, resulting in a cut down the middle of the affected area.

The anterior compartment fasciotomy is performed most commonly due to most cases occurring in this compartment. The fasciotomy procedure for the anterior compartment is performed through an initial 1.5-cm longitudinal skin incision is made with a No. 15 scalpel blade just lateral to the tibial crest centered over the proximal musculature. The scalpel is penetrated down to the fascial layer, once this is reached the initial fascial incision is made here with clear visualization of the fascia. The endoscopic fasciotomy guide is inserted, which is also a tool used during cardiothoracic surgery to harvest vein grafts. Next, the thermal ablation instrument is inserted through the guide which has uses for cutting, coagulation and vessel capture. The thermal ablation instrument is placed over the fascia of the affected compartment under endoscopic guidance[18]. The dilator tip of the ablating device is advanced distally above the fascia for the entire length of the release in order to develop the tissue plans and enhance exposure. The ablating instrument is then placed over the initial fascial incision made with the scalpel and slowly advanced distally while coagulating to release the fascia. As the fascia is being released the muscle beneath typically bulges through the opening created in the fascial layer. After this process is concluded, the wound is closed with No.2-0 Vicryl for subcutaneous approximation and a running subcuticular Prolene skin suture[18]. After the patient undergoes this surgical procedure weight bearing is allowed as tolerated with crutches. Return to activity and sports

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is permitted within four to six weeks after surgery. Although this is the primary treatment for exertional compartment syndrome, success rates are not exceedingly high. Fasciotomy performed for anterior and lateral compartments have about 80 to 100% success rate, being a 20% range. Fasciotomy performed for the deep posterior compartment has about 35 to 65% success rate due to increased complexity of anatomy in that area of the leg[9]. Additionally, there is a 15% surgical complication rate in athletes and military members. There is a possibility of recurrence of ECS in affected compartments of about 6 to 11%, which will be evaluated for a second fasciotomy procedure[9]. Although results vary in substantial ranges, a recent systematic review on fasciotomy for ECS concluded an overall success rate of 66%, satisfaction rate of 84% as well as return to full activity of 75%[19]. Each percentage is a significant amount over 50%, which concludes it to be overall successful in each aspect. This is the dominant procedure performed with the intent to fix exertional compartment syndrome, as being cured is not a guarantee. In addition to the fasciotomy, physical therapy is also recommended. Physical therapy is performed by Physical Therapists, health specialists who evaluate and treat human body disorders through promoting, maintaining and/or restoring health through physical examination[20]. Physical therapy is critical to perform after fasciotomy is done in order to reduce scar tissue which can cause adhesions causing the syndrome to redevelop. After the surgical wounds have healed, strength training and proper mobilization is focused on in order to optimize success of the fasciotomy.

There is another treatment method that has been developed recently and is still undergoing extensive research, however results have been promising thus far. Botulinum toxin A (BoNT-A), known as Botox, is commonly used in the treatment of muscle hypertrophy, and physicians have researched its effect with helping exertional compartment syndrome[21]. Botox is injected into the lower leg, specifically certain spots on the affected muscle to decrease the amount of swelling during exercise. The common procedure of Botox injection has been done guided through ultrasound imaging with a specific number of units of Botox depending on the patient, usually to the tibialis anterior muscle. A study was performed with abobotulinum toxin A injections into the anterior and anterior/lateral compartments in sixteen individuals with follow ups between three to six months. After the follow up evaluation fifteen of the tested individuals were asymptomatic. Fourteen of the individuals experience normal pressure levels within the affected compartment after exercise[21]. However, a negative effect of the Botox injections is that muscle strength can decrease due to the Botox "shrinking" the muscle to decrease swelling inside the fascia. In conjunction with the decrease of muscle size some individuals will experience muscle weakness. In this study, 11 individuals displayed decreased overall strength, however did not display weakness. In other studies, the Botox injections had to be repeated from four months to a year after the initial injection in order to keep pressure levels down and decrease symptoms. Although promising results have been displayed with Botox treatment for exertional compartment syndrome, further research needs to be performed in order to establish a safe and effective regimen for all patients.

Development of a Protocol for Exertional Compartment Syndrome

The body is interconnected and each body system is dependent on each other. Exertional compartment syndrome deals with the connection of the muscular system, the nervous system and the skeletal system. The muscular system is composed of specialized cells called muscle fibers with a function of contractility[22]. The nervous system is the major controlling, regulatory, and communicating system within the body[23]. In ECS the nervous system primarily deals with the nerves within the lower leg. The skeletal system is the dominant support structure for the body, also providing the body's shape and movement[24]. Through recognition of the body's interconnected systems a protocol for exertional compartment syndrome can be created to improve the detrimental effects it has on an individual's body and life. Further research of the overall anatomy of ECS and specific factors in particular systems can make a breakthrough in ECS treatment. The completion of the fasciotomy corrects the root problem, however with statistics indicating that ECS remains undiagnosed for up to two years, the anatomy of the body shifts in order to compensate for the constant trauma the lower extremities have been enduring in the interim. A protocol can be

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developed in order to treat the damaged anatomy and function of the body as a whole, thereby decreasing the recurrence of symptoms after fasciotomy. Typical issues with the anatomical aspect of patients with prolonged ECS are poor mobility of joints, lack of strength in major stabilizing muscles and tissue tightness below the hip muscles. Exertional compartment syndrome produces trauma to all of the lower extremities even though its presence may be restricted to one area of the lower leg. The increased pressure debilitates the functioning of the entire lower leg, causing soft tissue damage within the lower extremities as they must overly stretch and contract to compensate for the limited function and movement during exertion. An effective protocol to alleviate trauma and pain caused by exertional compartment syndrome would be to implement intense manual therapy, mobility stretching, and corrective strength training. This protocol would supply the body with the tools necessary to realign its anatomy and begin to function properly as each muscle and joint performs its own role without another section having to compensate for its function. This protocol would also supply a regimen specifically for patients diagnosed with ECS, because patients with ECS are currently treated for their symptoms and area of pain instead of being treated for the overall syndrome.

Manual Therapy for Protocol

The implementation of manual therapy would be highly effective in releasing fascia tension and restrictiveness, as well as decreasing build up of scar tissue post-surgery. Manual therapy is most often performed by physical therapists due to their education and certification for this specific technique. Manual therapy utilizes specific hands-on techniques without the assistance of devices or machines[25]. The hands-on technique is performed to improve tissue extensibility, increase range of motion of the joint complex, mobilize soft tissues, reduce soft tissue swelling, and change muscle function. Soft tissue within the body include muscles, nerves and tendons which are highly involved and affected in the diagnosis of ECS. Specific techniques performed through manual therapy include applying pressure in order to relax muscle tension, break up scar tissue and fibrous muscle tissue, reduce inflammation and promote circulation[25]. In this development of protocol physical therapists primarily target the muscle and connective tissue. Pressure to the tissue can help increase blood flow to decrease pain and promote optimal performance. Manual therapy has been concluded to be highly effective in chronic pain and is used to recover functional capabilities due to the release of tension within specific parts of the body[26]. Another technique involved with manual therapy is known as massaging. A massage is a hands on technique performed on the body in order to relieve pressure and tightness. A specific type of massage physical therapists are able to perform is known as the lymphatic drainage massage that relieves swelling that results from injury[27]. In exertional compartment syndrome and especially after fasciotomy, during exertion the muscle becomes visibly swollen. After repetitive exercising the compartment and muscle have a difficult time releasing the buildup of fluid and swelling. Therefore, a lymphatic drainage massage can be used to treat the intense swelling that occurs during exertion. This intense swelling can be painful as the build up will begin to block the movement of joints making it more difficult for the individual to perform functions such as dorsiflexion of the ankle. The shin bones are contracted and the ankle joint is flexed during dorsiflexion. To perform this technique physical therapists will elevate the patient's lower leg then use their hands to massage from the bottom of the affected compartment to the top. This optimizes lymphatic drainage of the build up of fluid and swelling to reduce symptoms. This is highly effective in providing release of discomfort or pain, and significantly improves performance. The combination of these techniques provides health and optimal performance to the patient, improving their symptoms to be less painful and more manageable when undergoing activity.

A subset of manual therapy can be performed through manual use of specific tools. This technique is defined as scraping, which is a treatment using tools enabling clinicians to efficiently locate and treat soft tissue tightness and injury[28]. The instruments used in scraping break up adhesion and restore normal tissue mobility to correct musculoskeletal issues which may be causing pain. This technique can be applied onto the affected compartment as well as surrounding muscles depending on the patient's diagnosis. A soothing cream is applied onto the area where scraping will be

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performed. The scraping treatment can be uncomfortable depending upon the level of tightness within the muscles and connective tissues. It is common for patients to experience discomfort and redness during the treatment, as well as potential sensitivity the day after[28]. Although it involves minimal discomfort, scraping is a beneficial technique that significantly improves functionality of the body and improves consistent pain. The methods of manual therapy can significantly reduce the overall pain experienced by patients diagnosed with exertional compartment syndrome.

Mobility Stretching for Protocol

The implementation of mobility stretching would be beneficial in the reduction of ECS symptoms and provide adequate performance in athletics as well as everyday life. Mobility itself is the combination of flexibility and strength, the sum making up your total movement capacity. It is defined as a fitness attribute and the ability to actively extend ranges of motion[29]. Mobility stretching has multiple benefits such as joint health and longevity as well as greater movement capacity. The protocol development will focus heavily on ankle mobility and hip flexor mobility. The ankle is the first major joint that absorbs shock when an individual's foot hits the ground while pursuing activity. If ankle mobility is lacking, the initial shock will be absorbed somewhere further up in the body contributing to various pains in the shins, knee, hip and back[30]. A different joint will be absorbing this shock which it was not designed to absorb and this is dangerous to the health of the compensating joint. Ankle mobility between both ankles should be relatively the same in order to promote equal distribution of the forces and proper balance. If one ankle has more range of motion, the forces will be unequally distributed throughout the kinetic chain causing the body to be unbalanced and forced to compensate[30]. Poor ankle mobility will affect an individual's gait which is how an individual walks, as well as their running economy[31]. In athletes diagnosed with ECS prime ankle mobility is critical due to the importance of the ankle joint involved in running. Poor ankle mobility can cause ECS to intensify and athletes to experience greater pain. Implementing mobility stretching for ankle mobility can significantly improve the symptoms caused by ECS through improvement of gait functionality. To introduce ankle mobility to the patient, important exercises are ankle circles that can be performed by using a foam roller that is placed under the ankle. To begin, the patient slowly rotates their ankle in a clockwise direction ten times and then repeats the motion ten times in the counterclockwise direction. The patient should focus on moving the foot and ankle and not engaging their legs. Another important mobility stretch is known as the ankle flexion plantar stretch. The patient begins by sitting on the floor or a table with one leg bent at the knee, with their heel on the floor, and the other leg straight[32]. A band will be looped around the front of the patient's foot, then the patient holds each end of the band with their hands. The foot will be pointed slowly forward and then back releasing collected tension. Another important ankle mobility stretch for ECS is ankle flexion (dorsiflexion) which uses a stretch band to flex the ankle by pulling the toes towards the body. The patient will sit on the floor with their legs stretched out in front of them while also having a secured band around a chair leg or a table leg, and then wrap it around one foot. The patient will slowly point their toes upwards towards herself and then return to the starting position. This will increase the mobility the ankle has when lifting the foot up which will be highly beneficial once swelling begins within the compartment, in order to have optimal mobility of the joint.

Hip flexor mobility is very important because the hip flexors are key muscles in stabilizing the pelvis and spine. They are able to create stability and are used in explosive movements such as running and jumping[33]. If the hip flexors are lacking in mobility this causes destabilization throughout the body by putting weight on different parts that are not equipped to handle the weight. The overuse of muscle groups presents through pain arising in certain areas of the body. Therefore, optimal mobility of the hip flexor muscles is very important especially for individuals and athletes with exertional compartment syndrome. Hip flexor weakness influences how the lower body moves by causing an imbalance of forces throughout the lower-leg muscle groups and contributing to compartment syndrome if mobility is lacking[34]. To increase hip flexor mobility, including a mobility stretch put in the protocol would be effective. This would involve the patient kneeling down on their left knee and putting their right foot in front of them. Their right hip and knee should make a

 doi:10.20944/preprints202403.0357.v1

ninety degree angle. Then the patient would put their left hand on their left hip, gradually pushing their hip forward. Their left hip should end up in front of their left knee[35]. Another mobility stretch to be performed to increase hip flexor mobility is for the patient to lie back down on an elevated surface, whether that is a couch or clinical table, using a strap looped around their foot of the one leg hanging off of the elevated surface. With their hands the patient will begin to slowly bring their foot and leg towards their head. This increases mobility and releases pressure in the area as the leg is "free floating" in the air during the stretch. Mobility stretching is incredibly important, especially for athletes, because it improves joint health allowing full mobility of joints and muscles to perform their functions correctly. Exertional compartment syndrome symptoms can be reduced significantly with increased mobility of the associated muscles and joints, because it alleviates compression and tightness which are factors that cause the symptom to intensify.

Corrective Strength Training for Protocol

The implementation of corrective strength training into the protocol would significantly improve consistent undesirable effects of exertional compartment syndrome for athletes. Corrective strength training is a technique that combines the understanding of anatomy, kinesiology, and biomechanics to address and fix movement compensations and imbalances to improve the overall quality of movement during workouts and in everyday life[36]. In this protocol the corrective strength training would primarily focus on strengthening the gluteus muscles, core muscles and hamstring muscles as well as and focusing on increase of overall body strength.

The gluteus, more commonly referred to as the "glutes", consists of three sets of gluteal muscles originating from the pelvis and inserting into the femur[37]. The three muscles are the gluteus minimus, gluteus medius and the gluteus maximus. The gluteus minimus is the smallest and deepest in the body compared to the other two gluteal muscles. The gluteus minimus is responsible for abduction of the thigh and stabilization of the hips and pelvis during walking, running or standing on one leg. The gluteus medius is the middle-sized muscle sandwiched between the gluteus minimus and the gluteus maximus[37]. This muscle is responsible for proper pelvis alignment during different movements and for adequate single-leg balancing. The gluteus maximus is the biggest of the gluteal muscles. This is one of the strongest muscles within the body. The gluteus maximus is responsible for stabilizing the pelvis and helping in hip rotation. It also is responsible for abduction and lateral rotation of the hips but also in hip extension, which pulls the leg backwards[37]. The glutes as a whole are important for most bodily actions such as walking, running, jumping, or simply rotating your hip joints. The strengthening of gluteus muscles is extremely important due to their contribution to improved balance, posture, muscle performance and lower back support which can reduce the risk of sports-related lower body injuries. If the gluteus muscles are lacking in strength the body will find another muscle to take over it's role, however it is not that other muscle's designed role so pain to the lower body will occur. The gluteus muscles are able to work individually and together to stabilize the lower half of the body to increase muscle performance, alleviating swelling and overuse of the lower legs. Therefore, exertional compartment syndrome symptoms can be reduced through the increase of gluteus strength which is able to stabilize the pelvis allowing equal weight on each side of the body as well as adequate performance of each muscle, so that one muscle is not compensating for another. Exercises such as squats, lunges and bridges should be introduced to the patient for the protocol. These exercises promote glute activation which stimulates the increase of glute strength. The squat exercise is very important in strengthening your gluteus muscles as well as the tendons, bonds and ligaments within the leg muscles. The squat exercise is performed from standing straight with feet shoulder width apart, and then lowering down as if the patient is going to sit in a chair, then with their heels the patient will push themselves up to strengthen the legs and come back to the upright standing position. The patient's core should be kept tight, keeping it engaged, and the patient should display adequate form keeping the shoulders straight with the back stabilized. In addition to strengthening the gluteus muscles, it engages multiple joints associated with the quadriceps, hamstrings, and calves. To perform a lunge the patient's torso must be kept straight with core tight, as they take a step forward lowering towards the floor as the knee is bent. The thigh of the leg that

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took the step forward will be parallel to the ground and the leg behind it will have the bent knee pointing towards the floor. The position is a split stance, the knee does not touch the floor which keeps the gluteus muscles engaged. The leg position is alternated between how many lunges the patient performs, such as stepping forward with the right foot first then the second lunge is performed with the left foot stepping forward. It is important to keep this form when performing the lunge exercise to make sure the gluteus muscles are engaged as well as minimal pressure on the knee. The bridge exercise is important because it is able to isolate the gluteus muscles. This exercise is performed by the patient lying on their back on a flat surface, their knees bent upward and shoulder width apart. The patient will then push through their heels to raise their hips off the floor until the hips are aligned with the knees and shoulders and then squeeze the glutes at the top for three seconds. The patient will then lower back to the ground to the start position. Each of these exercises are key for glute strengthening. These exercises are also beneficial for improving exertional compartment syndrome symptoms and pain occurrence. In this protocol, the patient would start off with bodyweight exercises and increase the weight every two weeks or upon evaluation every week. The squats and lunges would use lifting weights to increase weight, but the bridges would use bands. The tightness of the bands exerting pressure to hold the legs together increases as the patient lifts their hips and attempts to keep their feet separated shoulder width apart.

The hamstrings consist of a group of three muscles along the back of the thigh of the upper leg. The group of three muscles are the Semitendinous, Semimembranosus, and the Biceps femoris. The Semitendinous muscle is located at the posterior and medial area of the thigh. It also has a long tendon of insertion. This muscle's function is responsible for the extension of the thigh at the hip, flexion of the leg at the knee and internal rotation of the knee when the knee is flexed[38]. The Semimembranosus muscle is located on the posteromedial side of the thigh deep to the Semitendinosus muscle and medial to the Biceps femoris. This muscle primarily involves knee flexion, knee internal rotation and hip extension, with a secondary role in providing knee stability[39]. The Biceps femoris muscle lies in the posterolateral aspect, arising proximally by two "heads" defined as the long head which is superficial and the short head which is deep. The long head of the biceps femoris is responsible for flexing the knee, extending the hip, laterally rotating the lower leg when knee is slightly flexed, assisting in lateral rotation of the thigh when the hip is extended. The short head is responsible for flexing the knee and laterally rotating the lower leg when the knee is slightly flexed[40]. The hamstrings itself are skeletal muscles at the back of the thigh that cross the knee and hip joints. These muscles contribute primarily to functional motion such as walking or jumping. They are also important in athletics as they are a factor helping an athlete achieve speed, power and agility in different sports. Important factors of the hamstrings directly related to exertional compartment syndrome is that they are responsible for executing explosive movements because they shift the load from the knees to the hips[41]. In addition, they contribute to the ability to absorb the shock of movements involving high velocity or force, which is abundant in sports. Strong hamstrings are important because if they are weak and tight they will tug on the hip muscles causing them to tip forward, compromising functional movement[41]. Therefore, corrective strength training of the hamstrings in athletes with exertional compartment syndrome is important in order to optimize functional ability of the body. To strengthen the hamstrings an exercise that should be implemented into the protocol are single-leg Romanian deadlifts. To perform this exercise the patient will begin standing upright with their knees slightly bent, then raise one foot slightly off the ground extending their leg outwardly behind them. Their core must be kept tight and their back as straight as possible. As their leg is extending outward behind them, their torso will lower until their chest is parallel to the ground. Once, reaching this position be sure the patient squeezes their hamstrings and glutes together as they return to the original position. Another important exercise to strengthen the hamstring is the double leg Romanian deadlift. To perform this exercise the patient will stand upright with a dumbbell of light weight in each hand. The patient's feet should be shoulder width apart. The patient will begin to move their hips backwards and bend forward from their waist, keeping the dumbbells close to their legs and lowering to the floor. During this exercise it is important that the patient keeps their back straight to avoid injury. Once the dumbbells reach the bottom of the shin

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height, the patient will begin to straighten their legs while pushing with their heel back to the upright position. In the development of this protocol it is very important to include the hamstrings within the corrective strengthening section, due to their primary roles being involved in functionality of the body. In exertional compartment syndrome there is a lot of pressure on the lower leg, therefore strengthening the hamstrings and being sure the form is correct when doing so will be able to work towards alleviating any extra pressure put onto the lower legs.

The core is usually thought to describe one area of the body, however there are multiple major muscles within the core. The core includes five main muscles such as the pyramidalis, rectus abdominis, external obliques, internal obliques and the transverse abdominis[42]. The two vertical muscles are the pyramidalis and the rectus abdominis. The pyramidalis helps maintain internal pressure in the abdomen and it is small with the shape of a triangle. This muscle is located low in the pelvis area. The rectus abdominis is a pair of muscles going down the middle of the abdomen, stretching from the ribs to the front of the pelvis. This muscle keeps the body stable during any movements. In addition to these two vertical muscles the core consists of three flat muscles that are stacked on top of each other. The external obliques are the external pair of muscles located on each side of the rectus abdominis. These muscles are the largest of the flat muscles and are located underneath the internal obliques and the transversus abdominis. They run from the sides of the body into the middle allowing the torso to twist side to side[42]. The internal obliques are located on top of the external obliques inside of the hip bone. They are also located on the side of the rectus abdominis stretching from the side into the middle. These muscles aid the external obliques in rotation of the torso. The transversus abdominis is located deepest into the body of the flat muscles. Their function is to stabilize the torso and maintain internal abdominal pressure[42]. The core muscles as a whole work to improve coordination, balance and technical skills within athletics. As stated previously with each individual muscle they are able to increase stabilization in the torso and the body as a whole to reduce the risk of injuries. Strong core muscles increase better posture and balance which causes release of pressure on the lower half of the body which is critical to do for exertional compartment syndrome. In addition, if the core muscles are weak an athlete is more susceptible to increased fatigue causing decreased endurance and increase of injuries[43]. For the implementation of the protocol the patient would be instructed to perform exercises to strengthen and engage the core. An important exercise to increase core strength is a plank. A plank is performed by lying down on the stomach on a flat surface, usually with a mat on the floor. The patient will lift the arms up to be leaning on their lower arm, in which the elbow to the hand will be lying on the floor. The patient will lean on their toes lifting their body off of the mat, with their lower arm still lying flat on the mat. The patient will hold this position for thirty seconds until further progression. Another important exercise is the side plank. Starting on the right side first, lying on the floor with a mat and with the patient's legs stacked on top of each other. The patient's right arm will be bent with the lower half of their arm making a ninety degree angle with the rest of their body. The patient will then push up with their right foot and lower right arm to lift their hips off of the mat, therefore the weight is held up by the lower right arm and the right foot. This position will be held for thirty seconds until further progression. Once completed on the right side the patient will switch to the left side, performing the same technique as the right side just with the opposite arm and leg. The exercises are very effective in targeting the entire core, being sure to strengthen each muscle. In workouts for athletes it is often that isolated core exercises will be neglected to focus on full body strength training, which is thought to make the athlete stronger and better. However, neglecting specific isolating core exercise has detrimental effects as the entire body begins to become unbalanced. Therefore, implementing this into the protocol for ECS would be highly beneficial for the athletes affected, as their body will become better balanced and stabilized, relieving and additional stress compensations to the lower half of the body.

The development of a protocol for Exertional compartment syndrome is immensely important, because there is no specific treatment method in order to improve body functionality before or after surgical treatment. Most athletes and patients are treated for the symptoms exertional compartment syndrome produces. The syndrome is not dealt with as a whole. A factor that is not commonly recognized by physicians and physical therapists, due to lack of research, is that the anatomy of the

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body is completely shifted as exertional compartment syndrome continues to develop. The body begins to compensate in different ways due to the lower leg losing proper functionality. Fasciotomy is performed to correct the direct cause of the syndrome once it becomes incredibly restrictive to everyday activities. However, the anatomy as a whole is still affected by the effects of the syndrome. Therefore, developing a specific protocol combining manual therapy, mobility stretching and corrective strength training can alleviate painful effects induced by exertional compartment syndrome as well as allow optimal return to activities such as sports and intense exercising. The development of this specific protocol can improve everyday life functionality and overall health of the anatomical aspects of the patient.

Preventative Measures in Athletics

In the world of athletics pain is often ignored due to motivational quotes such as "No guts, no glory" and "No pain, no gain". It is often that an athlete is injured and is advised to ice their injury and be ready to go full on the next day. Most coaches and athletes do not recognize that pain when enduring extensive training is not always as simple as rest and ice. Unfortunately, most coaches lack the education of a variety of different injuries. This lack of education and knowledge often causes the coaches to push their athletes, not realizing they are severely injured. Athletes then begin to have fear instilled in them that any time off to recover from injury may have adverse effects on their performance and playing time. However, this usually leads to an even worse injury than the athlete originally acquired due to overuse of the injury and not receiving treatment. This is most often observed in younger athletes, which is actually crucial due to their bodies' continued development. Young athletes who continue to push through injuries usually have to retire from their sport earlier than expected due to their bodies becoming ill equipped to deal with the pain and pressure constantly experienced by their bodies. In the worst cases, their body never fully heals, inhibiting specific movement and basically forcing the athlete to stop participating in their sport. These instances happen more often than not, which is quite upsetting. Therefore, preventive measures can take place within the athletic world to prevent athletes from pushing through major injuries and having to deal with more severe injuries that could have been prevented. Preventive measures can be introduced to coaches through the attendance at an educational seminar before the start of the sports season. This seminar should be required for any coach and assistant coach of any sport team before the season begins. The attendance at this seminar will educate the coaches about the variety of injuries the athlete is most susceptible to from the specific sport they are coaching. In this seminar, less known injuries such as exertional compartment syndrome will be addressed and explained. Most coaches have absolutely no idea what ECS is and do not understand the severity of the pain and effects that an athlete is experiencing. Athletes should also be made aware of injuries they are susceptible to and the symptoms of each; thereby, once a symptom arises it may be treated early and additional injury may be avoided. In addition to more education and awareness of injuries such as ECS, athletes should be evaluated monthly to be sure their body is functioning properly and any pain they are experiencing is addressed. Also, a strength training program should be implemented on every sports team, but individual to each athlete. All athletes should be increasing their strength and mobility for the overall health of their bodies, not just to adapt to the stigma of being a "better and stronger athlete". Every individual athlete is different and so is their body, therefore they should be sure to perform exercises to increase their performance and focus on the health of their individual body. Each athlete may require different individual exercises to become healthier and stronger to perform better. The critical effects of exertional compartment syndrome can be widely avoided if it is recognized early on and awareness of the syndrome is increased, so athletes may receive prompt and adequate treatment.

Conclusion

Exertional compartment syndrome still requires further research to fully understand how exactly it occurs in individuals, specifically athletes. Research has been done on different treatments associated with fasciotomy techniques, however this has a focus on acute compartment syndrome and a subfocus on exertional compartment syndrome. Acute compartment syndrome usually has a

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greater focus because there is greater awareness due to its development within trauma injuries to the muscles and bones. Most patients with trauma injuries are evaluated for acute compartment syndrome. Exertional compartment syndrome develops blindly to the athlete, once the symptoms begin they are most often mistaken for a less severe injury allowing the syndrome to advance and the symptoms to become more severe. Therefore, with greater awareness of exertional compartment syndrome a protocol should be developed and implemented for athletes to receive better treatment and be able to excel in their sport and other activities.

A similar comparison may be made to concussions, as a protocol has been developed to treat concussions due to their increase specifically within sports. A concussion protocol is an organization's set of policies, tools, and assessments for caring for a concussion[44]. Different sports organizations, such as the National Collegiate Athletic Association (NCAA) have a specific protocol developed for concussions that must be followed if an athlete sustains a head injury. This is to prevent brain damage and ensure a full recovery back to sports and everyday life without any adverse effects. In colleges Athletic Trainers (ATs) are usually responsible for evaluating the athletes concussion through testing and if diagnosed with a concussion, they are responsible for implementing the specific protocol to the athlete to prepare them for recovery back to their sport. Athletic trainers are highly qualified, multi-skilled health care professionals who render service or treatment, under the direction of or in collaboration with a physician, in accordance with their education and training[45]. The protocol for concussions has been successful in treating athletes and allowing them to return safely to their sports without adverse effects from the injury. The development of a protocol for exertional compartment syndrome should be implemented similarly to prevent severe injuries the syndrome can have on the athlete. Treatment should be implemented for ECS as soon as symptoms arise in order to avoid invasive techniques such as fasciotomy.

Injury of an athlete can affect that person psychologically, not just physically. Serious injury to athletes in competitive sports can promote depression, tension, anger and low self-esteem[46]. The overall effect of injury further emphasizes that awareness of exertional compartment syndrome should increase. Treating this symptom early on with a clear protocol can greatly reduce the severity of the repercussions that the athlete may experience. Physicians should be made more aware of this syndrome and be motivated to actively research its effects in order to verify and implement the protocol. The implementation of this protocol by physicians and healthcare professionals responsible for treating athletes will allow those athletes to receive the best healthcare available, avoid serious physical and psychological issues and accordingly return to their sports as well as everyday life with optimal health.

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