Clinical Case Report Competition

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First Place Winner

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The effect of neuromuscular therapy (NMT) to the hamstrings in reducing neuromuscular risk factors leading to anterior cruciate ligament injury in a female athlete
Acknowledgments

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Abstract

The objective of this study was to determine whether neuromuscular therapy (NMT) as a modality, had any effects on modifiable neuromuscular risk factors leading to an anterior cruciate ligament (ACL) injury.

The participant in this case study was a 25 year old female elite ultimate frisbee player. She was considered in an at risk injury group due to her being female and the sport she plays. She also scored lower than 94% on the Star Excursion Balance Test (SEBT) composite score bilaterally indicating that she was also at a higher risk of a lower extremity injury.

A treatment programme was designed to evaluate the effects of NMT as a preseason intervention consisting of 5 treatment over two weeks with a follow up treatment two weeks after the fifth session. The main focus of the session was NMT to the hamstrings, consisting of twenty minutes per hamstring. Though supplementary techniques were used these were kept to a minimum in order to control the intervention of NMT.

The result from this case study show that NMT to the hamstrings can significantly reduce neuromuscular risk factors that may lead to an ACL injury. Improvements were seen in functional knee and hip flexion measured using kinematic data from a Single Leg Landing Test. As well as significant improvements in SEBT composite scores, with both right and left legs exceeding the 94% injury bench mark.

Key words: injury prevention, anterior cruciate ligament, Neuromuscular Therapy, hamstrings.
Chapter 1

Introduction

1.1 Background

Government statistics have shown that female participation in recreational sports and elite competitions has been on the increase in Canada (Ifedi, 2008). Due to the higher participation rates in sports and physical activity over the last 2-3 decades, it is not surprising that the prevalence of injuries has also been on the rise (Harber, 2012). Although it is not possible to avoid injury in its entirety, it may be possible to reduce the rates at which they occur.

One of the most commonly injured joints in female athletes is the knee. Of these injuries, ligament damage is the most common (Bollen, 2000). Compared to their male counterparts, females have been sustaining a significantly higher number of severe knee injuries, specifically to the Anterior Cruciate Ligament (ACL) (Hirst, et al. 2007). Female athletes participating in sports involving pivoting and jumping suffer ACL injuries at a rate 4- to 6 fold greater than males (Hewitt et al. 2005).

Rupture of the ACL is a serious, common and costly injury (Flynn et al. 2005). In America in 2004, the American board of Orthopaedic surgeons identified the reconstruction of ACL as sixth among the most common surgical procedures performed by all sports medicine doctors (Garrett, 2004). According to a study reported by Haverbush (2005), 2,200 ACL injuries to female collegiate athletes within one year resulted in costs of $44 million for surgery and rehabilitation. Following an ACL injury the rehabilitation process can take anywhere from 7- 9 months (Cluett, 2008). This can
be detrimental to an athlete, as they miss significant parts of the current, and even upcoming, season.

An effective injury prevention program would help minimize the disruption in an athletes participation and would also significantly reduce the financial burden on the athlete and health care system.

1.2  *Anatomy of the knee joint.*

For an effective injury prevention programme of the knee, it is important to understand the anatomy of the joint and its supporting structures.

While often classified as a hinge joint, the knee is more correctly classified as a double condyloid. It has movement potential both in flexion/extension and rotation (when the knee is flexed) (Whitton and Zernicke, 1998). The knee joint is the largest synovial joint in the body, allowing articulation between the femur and tibia which is weight bearing (Drake et al, 2005).

1.2.1  *Ligaments of the knee joint.*

The major ligaments associated with the knee (see fig 1.1) are tibial (medial) and fibular (lateral) collateral ligaments, and the anterior cruciate ligament (ACL) and posterior cruciate ligaments (PCL).
Fig 1.1, (Shiel, 2007). Anatomy of the left knee joint, in the anterior view, showing orientation of ligament that creates the knee joint.

From the diagram (fig. 1) it is seen that the ACL and PCL are housed in the intercondylar notch of the femur. The ACL runs posterior and superior from its attachment near the front of the tibial plateau to its femoral attachment at the posterolateral aspect of the intercondylar notch (Brukner and Khan, 2006). The PCL attaches to the posterior aspect of the intercondylar area of the tibia and ascends anteriorly to attach to the medial wall of the intercondylar fossa of the femur (Drake et al, 2005).

1.2.2 Cruciate ligaments.

The ACL and PCL are termed 'cruciate' ligaments because they cross each other in the sagittal plane between their femoral and tibial attachments (Drake et al, 2005). The ACL has a spiral arrangement of fibres which ensures that it is tensioned through varying degrees of knee flexion (Bird et al 1997). It works collectively with the PCL to stabilize the knee during dynamic movement. These two ligaments are intracapsular and provide stability to the knee joint in the frontal plane during varus and valgus loads. The ACL
primary function is to restrict anterior movement of the tibia relative to the femur (Whitton and Zernicke, 1998), while the PCL restricts posterior displacement (Drake et al, 2005).

1.2.3 *Muscle acting on the knee.*

Six superficial muscle influence knee joint stabilization: the vastus medialis (see fig 1.2), vastus lateralis (see fig 1.2), medial hamstring (see fig 1.3), lateral hamstring (see fig 1.3), medial head of the gastrocnemius, and the lateral head of the gastrocnemius (Drake et al, 2005).

![Fig 1.2](image) (Drake et al 2005). Anterior view of superficial muscles of the left legs quadriceps femoris.

The large quadriceps femoris muscles consist of three vastus muscles, medialis, lateralis and intermedialis, and the rectus femoris (figure 1.2). These muscles insert into the
margins of the patella as well as into the quadriceps femoris tendon. The quadriceps have been shown to work antagonistically against the ACL.

Collectively three muscles create the muscle group of the hamstrings, bicep femoris, semitendinosis and semimembranosus. In the diagram (fig 1.3) it can be seen that the hamstring can be subdivided into two section, the medial hamstrings comprising of the semitendinosis and semimembranosus, and the lateral hamstring comprising of the long and short head of the bicep femoris. The hamstrings has a crucial role in decelerating the forward motion of the tibia (Palastranga et al, 2002), without adequate contraction of the hamstring anterior draw of the tibia will occur which may lead to an ACL injury (Whiting and Zernicke, 1998).
Fig 1.4 (Drake et al, 2005). Posterior view of superficial muscles in the right leg.

From the diagram (fig 1.4) the gastrocnemius can be seen to be the most superficial of the muscles in the posterior compartment, and it originates by two heads, one lateral and one medial (Drake et al, 2005). Deep to the gastrocnemius is the soleus these muscles create the triceps surae group (Muscalino, 2005). The gastrocnemius and soleus both plantarflex the foot at the ankle joint and gastrocnemius will also assist in flexing the leg at the knee (Drake et al, 2005). These muscle have also been shown to have an effect on the ACL. Since the proximal tendon of the gastrocnemius muscle wraps around the posterior aspect of the tibia, its contraction could potentially strain the ACL by pushing the tibia anteriorly (Flemming et al, 2001). Conversely the soleus muscle is capable of acting as an agonist for the ACL (Elias et al, 2003), it is unclear how this occurs as the soleus attachment site is inferior to the knee.
1.3 Understanding predisposing risk factors.

As well as understanding the anatomy it is also important to identify predisposing factors. Four main categorical risk factors have been identified to attempt to determine the aetiology of an increased rate of ACL injuries in females; these are environmental, hormonal, anatomical and neuromuscular:

Environmental factors may be considered as external or extrinsic factors, that include meteorological, the type surface, footwear, and protective equipment like knee braces.

Hormones are thought to increase incidences of ACL injury by increasing ligament laxity for female athletes (Silvers and Mandelbaum, 2002). During a female’s menstrual cycle different hormones are released at different times, most notably the ovulatory phase (days 10-14 of menstrual cycle) which has been shown to be statistically significant in relation to occurrence of ACL injuries (Wojtys et al, 1998).

Anatomical factors are thought to effect the mechanical alignment of the lower extremity which contributes to the overall stability of an athlete’s knee (Griffin, 2007). These include increased quadriceps angle (Q angle) (Silvers and Mandelbaum, 2007), a smaller intercondylar notch size (Uhorchak, 2003), and the fact that females have a smaller ACL compared to males (Silvers and Mandelbaum, 2007).

Neuromuscular risk factors are related to altered movement patterns, altered activation patterns. It has been observed that women compared to men use less knee and hip flexion during landing and stop jump activities, this will cause a greater quadriceps activation than the hamstrings thereby increasing ACL stress.
Clearly the predisposing factors are multifaceted, some being unchangeable like hormonal and anatomical, while other are changeable like environmental and neuromuscular. Most significant for this study is neuromuscular as it is believed that massage may have a positive effect on these predisposing risk factors.

1.4  **Neuromuscular risk factors**

Research in the area of ACL injuries is increasingly focusing on the role of joint proprioception and muscle activity in promoting knee joint stability (Rozzi et al. 1996). It has been suggested that an altered neuromuscular strategies during the execution of sports movements, which manifest in resultant lower limb joint mechanics (motions and loads), may increase the risk of ACL injury in female athletes (Myer et al, 2007).

The balance of muscle power and recruitment between the quadriceps and hamstring muscles in landing a jump is essential to functional knee stability (Brikner and Khan, 2006), and crucial in preventing ACL injuries. An eccentric quadriceps muscle contraction can produce forces beyond those required for ACL tensile failure (Woo et al. 1999). The hamstrings in contrast, is ACL agonists, so any weakness, increased flexibility or delayed motor signal to the hamstring may increase the susceptibility to ACL injury (Boden et al. 2000). It has been identified that female athletes rely more on their quadriceps and activate their quadriceps first rather than their hamstring (Huston and Wojtys, 1996). This tendency may result in excessive stress placed on the ACL because an unopposed quadriceps contraction will displace the tibia anteriorly (Woo et al, 1991).
The altered muscle firing pattern is intrinsically linked to kinematic data, which shows that women use less knee and hip flexion than men during landing and stop jump activities, this is caused by a greater quadriceps activation than hamstrings which in turn will increase ACL stress (Chappel, 2007).

1.5 How can Neuromuscular Therapy (NMT) be effective in reducing knee and ACL injuries?

A successful ACL preventative massage therapy programme would attempt to reduce previously mentioned modifiable neuromuscular risk factors.

Within massage therapy there are a variety of modalities and techniques to select from. Within this case study NMT was used on muscles that have an agonistic effect to the ACL, specifically the hamstring group. NMT was chosen as the main modality as it enhances the function of joints, muscles and general arthrokinematics of the body (Sharkey, 2008).

NMT works by engaging the nervous and muscular systems to create reflex responses, namely the stretch reflex and tendon reflex (Braun & Simonson, 2008). The stretch reflex causes contraction of skeletal muscles in response to lengthening of a muscle, which is detected by muscle spindles. The tendon reflex controls muscle tension by causing relaxation before a muscle force becomes so great that the tendons are torn. This is detected by Golgi Tendon Organs (GTO) (Tortora & Derrickson, 2010). NMT stimulates both muscle spindles and GTO’s through out the treatment to create a physiological change (Sharkey, 2008). All muscular movements depends on the nervous system, which is the main control centre of the body. By using this physiological relationship between nerves and muscles, muscle length and kinesthetic
perception can be changed (Braun & Simonson, 2008).

NMT creates these changes following basic neurologic and physiological laws. The law of Facilitation states, 'the more the nervous system uses a certain neural pathway, the more likely it will use it again' (Pearlscot, 2012). In relation to ACL injury prevention, this means that working the muscles that have an agonistic effect to the ACL will facilitate more efficient neural pathway to the muscle. A more efficient neuromuscular pathway will reduce the delay of the motor signal to the muscle, reducing strain applied to the ACL. A more efficient hamstring will create functional knee stability, reducing the reliance on the quadriceps.

NMT is also governed by Hilton's law which states that 'the nerve supplying a joint also supplies both the muscles that move the joint and the skin covering the articular insertion of those muscles' (American Medical Heritage Dictionary, 2007). This will effect the proprioceptors, which have also been identified as a contributing factor in ACL injuries.
1.6 **Significance of study**

Currently there are no studies looking at the effectiveness of massage and NMT in reducing the chances ACL injuries. If massage can promote an increased joint proprioception and muscle activity in promoting joint stability and/or improve landing biomechanics it will lead to a reduction in chance of an athlete sustaining an ACL injury. This will reduce the financial burden on the health care system and reduce/eliminate time an athlete spends injured.

1.7 **Aims of study**

The aims of the study were:-

(a) To establish whether NMT can improve knee joint stability.

(b) Establish whether NMT can influence lower extremity biomechanics

1.8 **Hypothesis of study**

It is hypothesized that massage therapy will improve participants lower extremity landing biomechanics and improve knee joint stability thus reducing the chance of knee injuries. These will be demonstrated in two ways:

1. Improved knee joint stability shown in SEBT test results.

2. Increase knee flexion during lower extremity landing biomechanics.

3. Increased Hip flexion during lower extremity landing biomechanics.
1.9 **Definition of terms**

- ACL: Anterior cruciate ligament.

- Bilaterally: Relating to left and right sides of the body.

- Closed kinetic chain: The extremity remains in constant contact with an immobile surface. The hand or foot is fixed in space and can not move.

- Extension: movement which increases the angle of a joint, e.g. increasing the angle of the knee by moving the tibia away from the femur.

- Flexion: movement which decreases the angle of a joint, e.g. decreasing the angle knee by bring the tibia toward the femur.

- Kinematic: Relating to motion or movement of the body.

- NMT: Neuromuscular Therapy

- SEBT: Star Excursion Balance Test

- SLLT: Single Leg Landing Test
Chapter 2

Case History

The participant in this case study was a 25 year old female, she weighs 65.7 kg and is 170.1 cm tall. The participant is a non smoker with good dietary habits and a healthy lifestyle. She currently participates in 5-8 hours of physical activity each week. The participant has had no previous knee injuries but has experienced ankle sprains in her past. Currently the participant has no lower extremity orthopedic pathology.

The participant was selected as an ideal candidate for an ACL prevention program due to predisposing factor, that of being female and due to the nature of the sports she competes in.

The participant performs at an elite level in Ultimate Frisbee, having won 4 gold medals for Canada. Ultimate Frisbee is a sport requiring lots of pivoting and jumping maneuvers. Other sports the participant participates in regularly is co-ed soccer and badminton, these sport also require pivoting and jumping maneuvers.

As well being an elite athlete the participant also has a full time job as a chartered accountant. Due to poor posture whilst at work, the participant has been experiencing lower back pain in recent months.

Upon preliminary assessment it was found that the candidate had less than 94% composite score bilaterally in the SEBT (see 3.2.1) indicating that she was at 6.5% greater chance of sustaining a lower extremity injury.
Chapter 3

Method

3.1 Treatment

Treatment consisted of six massage therapy session lasting 75 minutes, this included approximately 15 minutes needed for assessment and objective testing (see 3.2), these were completed pre and post treatment. Each session were scheduled in the early evening, the earliest being 17:00 hours and latest 19:00.

Five of the session were completed over a two week period and the sixth and final session was completed two weeks after the fifth session. This schedule was selected as the five session would represent a pre season ACL intervention program. The sixth treatment allowed for a follow up assessment to establish whether the effect of the intervention had any lasting effect.

The main focus of the sessions was NMT to muscles that have an agonistic effect to the ACL, specifically the hamstrings. In each session 40 minutes were dedicated to NMT of the hamstrings, 20 minutes each leg. The remainder of the time supplementary modalities to NMT were used, these included myofascial release, joint mobilization, therapist assisted stretching and various Swedish technique (Appendix 1). No home care or remedial exercises were given to the participant, in order to control the intervention of NMT as much as possible.
3.2 Objective Tests

To establish whether NMT can influence modifiable neuromuscular risk factors two objective test were used, the Star Excursion Balance Test (SEBT) and the Single Leg Landing Test (SLLT).

3.2.1 Star Excursion Balance Test (SEBT)

The SEBT has been adapted from Plisky, et al. (2009) comparative study into genders, sports and competition level, as well as Filipa et al. (2010) neuromuscular training study.

The SEBT is a functional screening tool developed to assess lower extremity dynamic mobility. It requires neuromuscular characteristics including lower extremity coordination, balance, flexibility and strength (Earl & Hertel, 2001). Previous data has shown that female athletes with a composite reach distance on the SEBT of less than 94% of their limb length were 6.5 times more likely to have a lower extremity injury (Plisky et al. 2006). For these reason it was deemed valid to include as an objective measure for this case study.

To create the stance platform Duct tape was used to create a 'Y' shape (See fig 3.1) which made the anterior, posterior medial and posterior lateral reach direction. The posterior directions were positioned 135° from the anterior direction which meant 90° between the posterior directions. An empty tissue box was used as a reach indicator, this was pushed by the reach foot in each reach direction to create a measurement for that direction.
The case study participant received a verbal and visual demonstration of the SEBT. The participant was asked to reach in the anterior, posterior medial, and posterior lateral direction, while maintaining balance with the stance leg. Six practice trials were performed on each limb for each of the three reach directions prior to official testing. On the seventh trial the therapist recorded the measurement using a tape measure.

The trial was discarded and the participant had to repeat the testing trial if; unable to maintain balance, heel of stance foot did not remain in contact with floor or weight shifted onto reach foot.

The SEBT composite score was calculated by dividing the sum of the maximum reach distances in the anterior (A), posterior lateral (PL), and posterior medial (PM) directions by 3 times the limb length (LL) then multiplied by 100.

Composite score (%) = (A + PM + PL) / (LL x 3) x 100

The SEBT was performed pre and post every treatment session.
3.2.2 The Single Leg Landing Test (SLLT)

The single leg landing test has been adapted from Rozzi, et al. (1999) knee kinematic study, and Huston et al (2001) lower extremity neuromuscular study.

This test was selected for this case study as landing mechanics at the hip and knee have previously been suggested to reveal an insight into ACL injuries (Decker et al, 2003).

The landing test requires the subject to stand atop 59cm bench and drop not jump from bench land and to maintain balance on one leg (see fig 3.2). The height of the drop was chosen due to a significant difference ($P<0.05$) in knee kinematic being observed at as high as 60cm and as well at 40cm but not as low as 20cm (Huston et al 2001). All landings were performed barefoot to eliminate variable of shoe-surface traction.

Fig 3.2 Single Leg landing Test. Participant is stood on 59cm bench ready to perform single leg landing technique.
The subject was allowed two practice trials which preceded the three test trials. A trial was not considered for data collection if the subject was unable to maintain balance upon landing. This test was performed bilaterally.

To enable it to be easily identified during digitization, prior to testing yellow tape was used to highlight key joints; ankle, knee, hip, shoulder, were highlighted in this way (see fig 3.2). One camcorder (Sony HDV handycam, Japan) was set up directly 90° horizontally to the landing zone to recording movement in the sagittal plane. The three test trials were recorded, the clearest of which was used for digitization.

The data collected was analysed using Quintic (Quintic biomechanics V21, Coventry) (see appendix 3). Quintic is a sports biomechanical video analysis software, allowing video data to be analyzed at 29 fps (frames per second). Using this software kinetogram was produced by identifying markers at incidences of maximum knee and hip flexion (see appendix 3).

This test was performed prior to each treatment session.
Chapter 4

Results

4.1 Composite Scores from SEBT

![Composite Scores Chart](image.png)

Fig 4.1. Composite scores from SEBT.

From the data obtain from the SEBT and composite scores created, a positive correlation can be seen with the intervention of NMT to the hamstrings. Most notable was post treatment three where scores were consistency greater than 94%, which Plisky et al (2006) identified as a bench mark in lower extremity injuries. It can also be observed that after one treatment a dramatic improvement was seen, with the right composite score going from 91.1% to 93.6 and left composite score going from 89.1 to 92.9%. Improvement was seen between every pre and post treatment scores.
4.2 Hip Flexion

![Graph showing hip flexion angles over six sessions for right and left hips.]

Fig 4.2. Maximum hip flexion from data obtained in SLLT.

The data collected from the single leg landing test showed a reduction in hip flexion over the six session. The right hip went from 107.8° prior to first treatment to 86.5°, and the left hip went from 113.2° to 95.1°.
4.3 Knee Flexion

Fig 4.3 Maximum Knee flexion from data obtained in SLLT.

The data collected for knee flexion shows an overall reduction over the six session, however the data is very varied and it is deemed there is no significant results achieved in this area.

Also note worthy but not objective was the participants perception of her improvements. She reported faster recovery after activity, as well as feeling more agile whilst playing sport.
Chapter 5

Discussion

From the results of this case study it is clear that NMT to muscles that have an agonistic affect to the ACL, can reduce the effects of neuromuscular risk factors. Benefits were seen after the first treatment and a significant difference was seen after the third treatment.

The results from the SEBT composite scores significantly improved with the intervention of NMT to the hamstring group. Improvement in the SEBT composite score appears to be dependent on posterior medial reach scores (see Appendix 2). Moderate improvements were seen in anterior scores while only a slight improvement was noted in posterior lateral reach scores. The improvement in these reach directions has previously been attributed to improved neuromuscular control and dynamic balance (Filipa et al. 2010). It has been shown that improvements in SEBT scores is directly linked to increased knee and hip flexion on the stance leg (Robinson & Grible 2008). This is very interesting considering the results obtained in the SLLT.

The kinematic data from the SLLT was very interesting. It was expected that NMT to the hamstrings would have a greater effect on knee flexion as opposed to hip flexion, as this is its prime movement. However, on further contemplation this is to be expected as the SLLT makes the lower extremity a closed kinetic chain. Thus, the prime movement of the hamstrings in this case is hip extension. Therefore NMT to the hamstring group will promote hip flexion through eccentric contraction of the hamstrings. This may also
explain the varied data with regard to knee flexion. This is merely a theory as there was no data collected on muscle activity.

The kinematic data alone has been found to be very informative. However, it has been identified that 'the likelihood of knee injury occurring is most likely to be predicted through integration of both alignment and position of lower extremities as well as magnitude and direction of forces imposed upon' (Kernozek et al. 2005). A protocol that would incorporate these areas would require specialist equipment, like a force plate to assess ground reaction forces and surface electromyography to measure muscle activity. This would not be a cheap methodology and would require significant funding, which this case study did not have.

With regards to the 6th follow up treatment the two week gap between the initial 5 treatments did not have a detrimental effect on the results. Both right and left composite score did reduce slightly but were well above the 94% bench mark, that has been shown to be significant in lower extremity injury rates. As for hip flexion there was a marked improvement over the two week break. It is unknown why this occurred.

The fact that the two week break had minimal effect on results is an indication that NMT intervention has a lasting effect. More research is needed in this area as it will be a valuable indicator in how often NMT should be used. With this information a therapist will be able to create a treatment plan to optimize the benefits of NMT. The results from this study would indicate that an athlete should have 3 to 5 pre-season treatments with follow up treatment every two weeks for the duration of the season.
The focus of this study was on injury prevention, however there was little thought in what effects NMT has on performance. An effective injury prevention programme would not be popular with many athletes if they noticed a decline in performance. Though the participant reported noticing improvement in agility, there is a need to use an objective agility test to see if NMT has a negative or positive effect on performance.

The goal of this study was the evaluate intervention to NMT to the hamstring, which provided interesting results with regard to injury prevention. However it is believed even better results could be achieved by taking a more integrative approach. Considering the many variables that effect the knee joint, a more 'global' approach could address these areas, as a opposed to the 'local' approach of treating only the hamstring group. Areas to consider would be any postural dysfunction like pelvic alignment, as well as releasing hypertoned muscles that have an antagonistic effect to the ACL like the quadriceps group. It is also pertinent to compliment treatments with remedial exercises such stretching and strengthening exercises.

Mandelbaum et al. (2005) suggests key components to ACL injury interventions are education, stretching, strengthening, plyometrics, and sports-specific agility drills designed to replace the traditional warm-up. The results of this case study now also indicate the inclusion of NMT to the hamstrings, may be an effective addition to any ACL intervention.
Chapter 6

Conclusion and Recommendations

The results indicate that NMT to agonistic muscles of the ACL, specifically the hamstrings, has a positive effect in reducing neuromuscular risk factors that may lead to an injury. For this reason it is recommended that NMT to the hamstrings be used as a modality with any female athlete performing in sports that put them at risk with jumping and pivoting movements.

However it is not a be all and end all treatment. The exact circumstances leading to an ACL injury is multifactorial. A prevention programme needs to address the many variables that come into play. It needs to treat any dysfunction with a global perspective and compliment the treatment with remedial home-care exercises.

Future research in this area could make the following improvement:

- Have a larger subject group, assessing the benefits over a whole season.
- Have a protocol that measures muscle activity and ground reaction forces.
- Assess what effect NMT to the hamstrings has on performance.
References


# Appendix

## Appendix 1  Summary Treatments

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Appendix 2 Raw Data from SEBT

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Appendix 3  Quintic video analysis

TX1 Right  TX2 Right

TX3 Right  TX4 Right

TX5 Right  TX6 Right
Appendix 4 Data from Single Leg Landing Test
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