WHITE PAPER

Evolution of a Successful New Hamstring Rehabilitation Protocol to Reduce Hamstring Injury Recurrence

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Evolution of a Successful New Hamstring Rehabilitation Protocol to Reduce Hamstring Injury Recurrence

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Two years ago, the orthopedic surgeons and therapists at the Nicholas Institute of Sports Medicine and Athletic Trauma (NISMAT) began seriously questioning conventional hamstring rehabilitation strategy. If it was as effective as commonly believed, athletes should not experience the high rate of recurrence reported internationally in a wide range of professional and amateur sports.

As a result of those observations, and those of others who have attempted with different degrees of success to reduce recurrent hamstring injury, the NISMAT team has developed a new lengthened-state eccentric dynamometer-based rehabilitation strategy for isolating the injured leg, and objectively determining when an athlete is ready to return to play. That protocol has been validated with a prospective 50-subject peer-reviewed study in which all compliant patients have been free of recurrent hamstring injuries at least two years later. This white paper explores the rationale for the new NISMAT protocol, the evidence from others on which it was based, and summarizes the results of our study.

Background: A continuing cycle of injury and reinjury

The 2015 NFL season illustrates the significant hamstring injury incidence:

- Muhammad Wilkerson, defensive end for the New York Jets, was one of six of that team's players sidelined in the preseason with hamstring strains.
- Dallas Cowboys wide receiver Dez Bryant and Denver Broncos outside linebacker DeMarcus Ware have been compromised by chronic hamstring strains.
- Miles Austin, formerly of the Dallas Cowboys, Cleveland Browns and Philadelphia Eagles has been plagued with chronic hamstring injuries since 2011; missing an average of five to six games. This history of injury and reinjury has played a significant role in shortening his once Pro Bowl caliber career.
- Former Houston Texans and league leading running back Arian Foster has a history of chronic hamstring injury.
- And on September 20, 2015 Chicago Bears quarterback Jay Cutler, signed in 2014 to a seven-year, $126.7 million contract, injured his hamstring while trying to tackle an opposing player following an interception.

Chicago Bears quarterback Jay Cutler an instant before injuring his hamstring attempting a tackle following an interception.

Hamstring strains are common in football and other sports that require a change in direction, kicking, acceleration and/or sprinting. Some of the many hypothesized risk factors include lack of proper warm-up, ham-to-quad ratio, and muscle fatigue – and the risk of recurrence is widespread.

- Christopher Ahmed, team orthopedic physician for the New York Yankees, reports that hamstring injuries account for 29% of all injuries in pro baseball. These injuries lead to prolonged impairment and have a reinjury risk of 12% to 31%.[1]
- In a study of UEFA (United European Football Association) injuries, hamstring strain was the most common diagnosis. A typical 25-player squad can expect about seven hamstring strains each season; thigh strains representing 17% of all injuries. Re-injuries constituted 12% of all injuries, and they caused longer absences than non-reinjuries (24 vs. 18 days, $p<0.001$).[2]
- Hamstring strains data were analyzed from the NCAA Injury Surveillance Program during the 2009-2010 to 2013-2014 academic years. Men's football, men's soccer, and women's soccer contributed the greatest proportion of hamstring strains (35.3%, 9.9%, and 8.3%, respectively). Most hamstring strains were non-contact related (72.3%). Of all hamstring strains, 12.6% were recurrent, 37.7%

resulted in a time loss of less than 24 hours, and 6.3% resulted in a time loss of more than three weeks.[3]

Lost playing time means lost money for professional athletes and teams, but the impact on collegiate sports funding can be very significant. In 2012, the University of Texas earned more than $103 million from football; Michigan earned more than $85 million, and Alabama, Florida and Georgia, between $74 million and $81 million.[4] For high school athletes, missing sectional playoffs due to a recent or recurred hamstring strain can mean loss of the visibility needed to earn a highly valued four-year scholarship at a top football college, and thus, a possible professional career.

Recurrent hamstring strain risk: Prior injury

In a landmark study of 508 amateur soccer players,[5] Engebretsen and colleagues performed a battery of tests including hamstring sensibility, hamstring strength, jumping ability and running speed, and performed eccentric testing. The only significant risk factor for reinjury that the investigators could identify in these 508 athletes was a previous hamstring strain - in fact, a hamstring strain in the prior year doubled the risk of a recurrent hamstring strain.

The Engebretsen recurrence-risk observations have been documented in many sports:

- *Professional Soccer.* Eighty-three percent of injuries affected the biceps femoris while 11% and 5% occurred to the semimembranosus and semitendinosus, respectively. Reinjuries (N=34/207) constituted 16% of injuries. Reinjury caused significantly longer absences than did first-time strains.[6]

- *Professional Australian Rules Football.* Hamstring injuries have the highest recurrence rate of all injuries, 34% of the incidence of new hamstring strains. Overall, the rate of recurrent injuries is 17% of the rate of new injuries.[7]

- *Professional American Football.* In total, 16.5% (n = 283) of 2010 hamstring injuries, including 19.7% of regular-season injuries and 13.8% of preseason injuries, were reinjuries. During the preseason, the reinjury rate was 12.7% (n = 91) for practices, and 17.6% (n = 35) for games. For the regular season, the reinjury rate rose to 22% (n = 40) for practices and 19.1% (n = 115) for games.[8] An NFL combine examined bilateral quad-hamstring ratio and lumbar posture control, and came to the same conclusion: the only consistent risk factor for hamstring injury is previous hamstring injury.[9]

- *Professional Baseball.* In the major leagues, 50 hamstring strains averaged 27 days missed. Base running, specifically running to first base, was the top activity for sustaining a hamstring strain in both major and minor leagues, associated with almost two-thirds of hamstring strains. Approximately two-thirds of these injuries, in both the major and minor leagues, resulted in more than seven days of time loss. Approximately 25% of these injuries kept the player out for one month or longer. History of a previous hamstring strain in the prior year, 2010, was found in 20% of the major league players and 8% of the minor league players.[10]

Miami Marlins Giancarlo Stanton pulls hamstring running out a bunt against Mets. Most baseball hamstring strains occur at first base.

Many recurrences likely result from historic lack of objective criteria for determining when it's safe for an athlete recovering from a hamstring strain to return to play. A recent paper in the British Journal of Sports Medicine shows that MRI is totally useless in predicting grade of strains and in predicting safe return to play.[11]

Conclusion: Most recurrent hamstring strains likely result from shortcomings in the most generally applied rehabilitation protocols.

Reexamining our rehab protocol

In rehabilitating hamstring strains, physical therapists historically start with isometric contraction, from mid-range to short range to a lengthened range. And then, they progress to isotonic against-gravity exercise, then isotonic against resistance, then isolated eccentrics – and then, functional eccentrics.

NISMAT and PRO Sports Physical Therapy formerly utilized similar criteria for rehabilitation and determination of safe return to play. Their protocol change, based on literature and a peer-reviewed study results, is the addition of lengthened-state eccentrics.

In the first phase of rehabilitation, our goals are to:

- Protect healing tissue
- Minimize atrophy and loss of strength
- Prevent motion loss while avoiding development of an antalgic (pain-avoidance) gait

The NISMAT physiologic objective is to encourage fiber alignment at the site of injury with submaximal isometrics, first in the mid-range, then in the shortened range, then in the lengthened range. Through that period, NISMAT clinicians concentrate on keeping the athlete in minimal pain, to avoid reinjuring the fibers. Modalities such as ice, pulsed ultrasound, and laser are commonly utilized in the acute stage of hamstring rehabilitation. In this phase, treatment should focus on protecting the injury and minimizing range of motion and strength loss. The hamstring should not be stretched into a painful range at this time, although hip and knee ROM should be maintained.

At 48 hours post-injury, the athlete may begin pain-free submaximal isometric strengthening with a set of isometric knee contractions at 30°, 60°, and 90° of flexion by placing the injured limb on top of the contralateral limb and contracting the strained hamstring. This exercise can be replicated at home, beginning with exercise at 90°, slowly moving to about 20° to 30° short of full extension. That exercise aligns fibers and increases the strength of the lateral adhesion of fibers that protect the injured fibers from stump separation. It will allow scar tissue between fractured muscle fibers to achieve sufficient strength while avoiding separation of fiber stumps. By day 10-14 post-injury, scar is actually stronger than the fibers.[12]

Phase 1: Therapeutic exercise

The functional goals of this phase are to normalize gait and to obtain knee flexion strength at greater than 50% of uninjured length upon manual muscle testing at 90° of knee flexion.

Daily therapeutic exercises can include:

- Stationary bike
- Single-leg balance
- Balance board
- Pulsed ultrasound

The milestone here is pain-free isometric and isotonic contractions at a short and intermediate muscle length. The duration of Phase 1 depends on the injury grade. Some grade ones can complete the NISMAT Phase 1 in three to four days, but some athletes with grade twos and threes can take weeks. If pain constrains such exercise in Phase 1, the only rehab modality is rest, to minimize injury and maximize potential for next-phase intervention – which means, no stretching. Once these milestones are met, the athlete may begin the next phase.

Phase 2: Preparation for return to sport

The goals of the second phase are to:

- Progressively regain strength throughout the range of motion
- Improve neuromuscular control of the hips and pelvis in preparation for sports-specific movements.

End-range lengthening should be avoided if painful in this stage. The athlete may begin to strengthen both concentrically and eccentrically at this time. Eccentric training can be achieved using an isokinetic dynamometer, if available, and perform exercises such as the straight-leg deadlift, single-leg windmills and the Nordic hamstring exercise.

- *Eccentric single-leg windmill without weights:* Patient stands with the uninjured leg on a chair or fixed surface and reaches down in a diagonal plane while keeping stance leg straight and maintaining lumbar lordosis.

- *Nordic hamstring exercise:* Clinician holds the patient's feet while in tall kneeling. The patient slowly falls forward while maintaining neutral hip posture until he or she can't control descent any longer and then pushes back into starting position with upper extremities.

After a dynamic warm-up, other Phase 2 rehab activities can include:

- Isolated eccentrics at short and intermediate lengths
- Nerve glides
- SLS with ball toss
- Weighted dead lifts

- Soft-tissue mobilization, instrument assisted soft-tissue mobilization
- Shuttle jumps
- Lateral and retro bandwalks

At the completion of Phase 2, the athlete should have full strength upon manual muscle testing (5/5) or be within 20% of the uninjured leg in the zero to 90° range when measured with a handheld or isokinetic dynamometer. S/he should also be able to jog at a moderate speed both forward and backward without pain. Our clinical milestone to move them to Phase 3 is pain-free maximum resistance with eccentrics at short and intermediate lengths. This is also our criteria for return to light practice – defined as feet-forward activities.

- For a female soccer player, light practice is dribbling a ball, not reacting to an offensive player.
- For a football cornerback, it's similar feet-forward activities, not reacting to the receiver.
- For football receiver, it's going out for a pass, making a cut, and catching a ball – not reacting to a defensive back in front of them.

Phase 3: Intensification of Phase 2 plus eccentric training in maximum lengthened state

The NISMAT Phase 3 protocol emphasizes Phase 2 exercises with increase in load, intensity, speed and volume – and adds eccentric training in the maximum lengthened state.

Phase 3 is really where NISMAT changed its hamstring rehabilitation protocol, at least in part in response to the findings of Schache and colleagues[13] who observed a dramatic increase in biomechanical load imparted onto the rectus femoris and hamstring muscles during initial swing and terminal swing – which they theorize explains rectus femoris and hamstring muscle strain injuries common in sports that involve repetitive bouts of sprinting.

From the data in that study, we concluded that hamstring injury prevention or rehabilitation should be preferentially based towards strengthening exercises that primarily involve eccentric contractions performed with high loads at longer muscle tendon lengths. We tested that concept with a well-controlled 50-subject study at the Nicholas Institute.

Goals of our Phase 3 protocol are:

- Symptom free (pain/tightness) during all activities
- Normal concentric and eccentric hamstring strength through full range of motion
- Improved neuromuscular control of trunk and pelvis
- Integration of postural control into each athlete's sport-specific movements

During Phase 3, we protect the athlete by training within symptom-free intensity, and the use of post-exercise icing after each session, typically for 10-15 minutes as needed.

Criteria for return to play

During Phase 3, NISMAT criteria for return to sport includes:

- Full strength without pain in lengthened-state testing position
- Bilateral symmetry in knee flexion angle of peak torque
- Full range of motion without pain
- Replications of sport-specific movements at competition speed without symptoms

Therapeutic exercise during this phase (4-5 days/week) typically involves:

- Treadmill moderate to high intensity as tolerated
- Hamstring dynamic stretching
- Isokinetic eccentric training at end ROM (in hyperflexion)
- Soft-tissue mobilization, instrument assisted soft-tissue mobilization
- Plyometric jump training
- 5-10 yard accelerations/decelerations
- Single-limb balance windmill touches with weight on unstable surface
- Sport-specific drills that incorporate postural control and progressive speed

Role of eccentric hamstring strengthening

Studies by Arnason and colleagues[14] and Peterson and coworkers[15] showed that eccentric hamstring strengthening using the Nordic hamstring exercise may be effective in preventing new and recurrent hamstring strains among athletes who had already returned to play. However, the Nordic hamstring exercise is difficult to introduce in rehabilitation of hamstring strains because:

- It requires high-force production, and the movement is difficult to safely control.
- It must be performed with both legs at the same time, so the uninjured side can compensate for the injured side.
- It is not performed at a long-muscle length.

The Scandinavian experience strongly suggests that the Nordic hamstring exercise is less effective in preventing injury in athletes with a history of hamstring injury (45.8 injuries/100 players) versus players with no previous hamstring strains (3.8 injuries per 100 player-seasons).

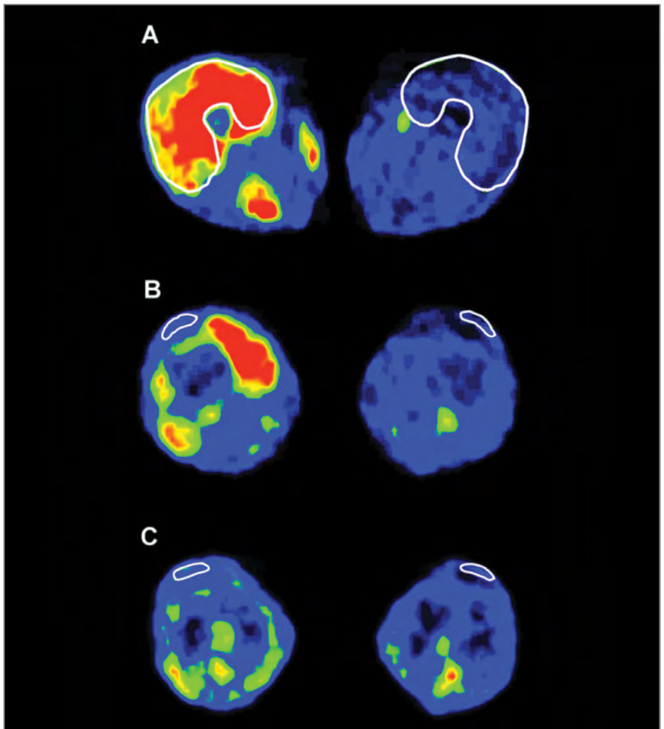

Figure 1. Positron emission tomography (PET) images from the regions of quadriceps muscle (A), quadriceps tendon (B) and patellar tendon (C) in the exercising and resting leg of one subject. White lines show the regions of interest. (From Kalliokoski et al. 2005.)

Additionally, Kjaer and associates[16] demonstrated with PET scanning that chronic loading of tendons with physical training leads both to increased collagen turnover as well as to some degree of net collagen synthesis (see figure 1). The investigators report those changes modify the mechanical properties and the viscoelastic characteristics of tendons, decrease their stress-susceptibility and probably make them more load-resistant.

Thus, isolated unilateral eccentric training in a controlled manner is needed in rehabilitation of hamstring strains – and so, lengthened-state eccentric training is performed at NISMAT using the Biodex™ System 4 dynamometer with the use of accessories that simplify placing the patient into hip flexion.

Hamstring rehab with the Biodex System 4

In its most common application, the Biodex System 4 passively extends and flexes the knee into the end range of motion. The patient resists the passive motion as the knee is extended. It is imperative that the hip is positioned in flexion as the knee extends to ensure the hamstring is truly at a lengthened state.

While eccentric hamstring training is commonly performed on the Biodex dynamometer, it is typically performed in the seated position with the range of motion from approximately 90° knee flexion (short-muscle length) to full extension (longer muscle length). However, this position does not place the hamstring near its maximum length – and thus, applies minimal stretch on the muscles at full extension.

Our Biodex protocol was developed in response to three documented observations:

1. Hamstring strains often occur in positions of significant stretch
2. Sprinting is a common mechanism for hamstring strains
3. Hamstrings work eccentrically at a high intensity in a stretched position while sprinting

Therefore, we hypothesized that rehabilitation should provide eccentric strengthening with the hamstrings in a maximally stretched position at the knee and the hip simultaneously – a state commonly described in rehabilitation as the lengthened state.

Inspiration for NISMAT protocol

NISMAT clinicians were encouraged to explore a potentially superior technique of increasing hamstring strength in the lengthened state by a 2004 study[17] by Brockett and colleagues at Monash University in Australia.

Brockett and colleagues had theorized that the optimum lengths of previously injured hamstrings are shorter and therefore more prone to eccentric damage during exercise than uninjured muscles. To test that theory, the investigators used isokinetic dynamometry to compare the mean optimum angle for peak torque in nine athletes with a history of unilateral hamstring strains with both the optimum angle for their uninjured leg, and with muscles of 18 uninjured athletes.

- The previously injured group included nine athletes; eight male and one female. Five males were AFL players (age range 26–33 years), all of whom had had a clinical history of multiple hamstring strains over the last four to five years. The investigators defined an incident of hamstring injury as one that led the athlete to miss at least one week of training or competition. Strains ranged from grade 1 to 3 tears.
- The second group included 18 athletes (all males) 19–28 years old. They were all AFL players, and none of them had a previous history of hamstring injuries or any other leg injuries that might complicate interpretation of the data.

The investigators used a Biodex System 3 to generate angle-torque curves – a measure of the torque as a function of knee-joint angle produced when the muscle is maximally activated during isovelocity shortening.

- Subjects were seated on the Biodex dynamometer with their hip joint at approximately 90° flexion and their upper bodies secured with dual crossover straps as well as a waist strap. The range of motion at the knee was approximately 110°.
- Both legs were tested separately and in random order.

The testing protocol consisted of seven repetitions of knee extension and flexion performed at a velocity of 60° per second while subjects exerted a maximal effort. Torque values from the seven repetitions were extracted and sorted according to the direction of movement and knee angle.

- *Without prior injury*. An example of angle-torque curves for a subject without prior injury (see figure 2). Values for hamstrings of the right leg indicated an optimum angle of 32.0° and for the left leg 29.9°.
- *With prior injury*. An example of an angle-torque curve from a subject with a previous history of a hamstring injury in the right muscle (see figure 2). This muscle had an optimum angle of 53.5°, which differed by almost 16° from the optimum of hamstrings on the left, uninjured side (37.5°), so that torque generated by the previously injured muscle peaked at a much shorter length than on the uninjured side. And yet, the value of peak torque for the previously injured muscle was higher, 71 vs. 65 N·m for the uninjured muscle.
- *Peak torque vs. torque angle*. On average, peak torque in uninjured subjects was ~30° versus 41° in the injured subjects.

The Monash investigators concluded that:

- The only significant difference in hamstrings of previously injured players is a short optimum angle – a trend consistent with the view that muscles with shorter optima are more likely to reinjure due to microscopic damage from eccentric exercise, which may increase the risk of a subsequent, more serious strain injury.
- During eccentric contraction, sites of prior injury act as foci for further damage, including the tearing of membranous structures, local release of calcium ions, and development of injury

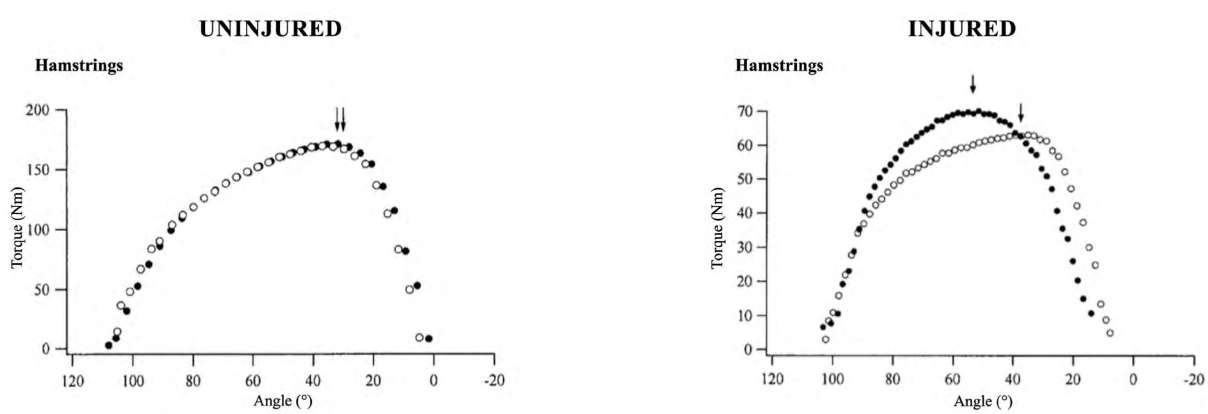

Figure 2. Comparison of angle-torque curves of an uninjured subject (left) versus one with a previous unilateral hamstring strain. Previously injured side is represented by the filled circles and the uninjured side by the open circles. Arrows indicate angle at which peak torque occurred. (From Brockett, et al. 2004.)

contractures. The size of the lesion continues to grow during repeated eccentric contractions, and a point is reached where fibers rupture, leading to a tear across the muscle. Because tendon is physically stronger than muscle fiber, a tear in a pennate muscle that reaches the aponeurosis will continue longitudinally along the aponeurosis.

- Conclusion: The critical factor is optimum angle of peak torque, not absolute peak torque.

The NISMAT study[18]

While eccentric hamstring training is commonly performed on an isokinetic dynamometer, it is typically performed in the seated position with the range of motion from approximately 90° knee flexion (short-muscle length) to full extension (longer muscle length). However, this position does not place the hamstring near its maximum length and there is minimal stretch on the muscles at full extension.

The purposes of this study were twofold:

- Determine whether a progressive eccentric strengthening program during hamstring strain rehabilitation restored isometric knee flexion strength relative to the contralateral side, and whether it restored the angle-torque relationship relative to the contralateral side, or shifted it to a longer functional muscle length (rightward shift in the length-tension relationship).
- Document the reinjury rate after return to sport. It was hypothesized that athletes who completed the rehabilitation program would demonstrate a rightward shift in their angle-torque relationship and have a low rate of injury recurrence.

The study group was comprised of 50 athletes (30 men, 20 women) diagnosed with a unilateral hamstring strain that occurred during sports performance or recreational exercise (age 36 ±16 years). Twenty-five subjects had a previous hamstring strain greater than three months ago.

Details of hamstring strains. Among the 50 subjects:

- Three were grade 1 strains, 43 were grade 2 strains, and four were grade 3 strains.
- Twenty seven hamstring injuries were proximal, 14 were midsubstance injuries and nine were distal injuries (six lateral, four medial).
- The mechanism of injury: 38 cases resulted from sprinting sports, 12 in non-sprinting sports or other activity injuries.
- At the time of injury 32 of the athletes were involved in recreational sports/exercise and 18 were involved in competitive sports (two professional, two college, ten high school, four club).

All athletes followed the same three phase rehabilitation protocol described earlier.

In Phase 2, isokinetic eccentric contractions were performed in the seated position at 0.35 rad/s (20°/s) progressing from submaximal to maximal contractions based on athletes' tolerance during contraction.

Performing lengthened state eccentric contractions on the Biodex System 4 to evaluate risk of reinjury and determine safe return to play.

In Phase 3, isokinetic eccentric contractions were performed in a lengthened state. Athletes were progressed from submaximal to maximal contractions.

- These contractions can be achieved on the Biodex System 4 by having athletes seated with the trunk upright or slightly flexed forward (e.g., flexed 80°-90° relative to horizontal) and the thigh flexed toward the chest (e.g., flexed 20°-40° relative to horizontal). To achieve the right degree of lengthened state, Biodex offers Hamstring Attachments so that the leg can be precisely positioned to apply sufficient stretch. Most individuals are unable to reach full knee extension with passive stretch due to passive muscle tension.
- In lengthened state, eccentrics on the Biodex dynamometer in passive mode can move the subject's leg through the range of motion while the therapist urges, "Resist, resist, resist, resist, resist, resist, resist." At the start of these exercises, the

therapist may need to shorten the range of motion to keep the subject in a pain-free range. As rehab progresses, s/he can lengthen the exercise range, to increase strength in the lengthened state.

Angle-torque (length-tension) relationship. Prior to discharge from physical therapy, all athletes in the trial performed an isometric knee flexion strength test in the same seated position in which lengthened state eccentric contractions were performed (see figure 3).

- Athletes who chose not to finish the rehabilitation program or had to stop for other reasons were asked to return for isometric strength testing.
- Strength was assessed bilaterally at 80°, 60°, 40°, and 20° knee flexion to provide a measure of the length-tension relationship. For most subjects in this test set up, the knee flexion angle was 40° when the dynamometer arm was horizontal (parallel to the floor).
- Limb mass and torque due to passive hamstring tension were subtracted from torque values at each angle to provide a measure of hamstring contractile torque production only. Two maximal contractions were performed at each angle progressing from short- to long-muscle lengths.

Reliability for the isometric strength testing protocol was assessed in ten healthy volunteers who performed the protocol on two separate occasions at least a week apart.

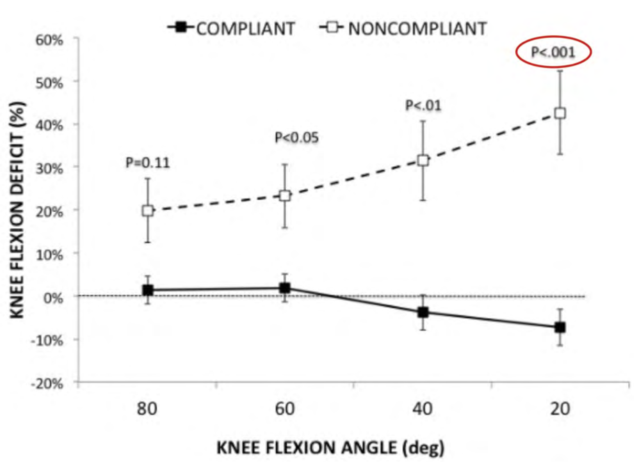

Figure 3. Isometric knee flexion strength deficits at short (80°) to long (20°) muscle lengths for compliant and noncompliant athletes. Significant strength deficits apparent in noncompliant athletes but not in compliant athletes (Compliance effect P<0.001) with differences in deficits between compliant and noncompliant athletes more evident at longer muscle lengths (Compliance x Angle P<0.001).

Critical results of study: Compliant athletes suffered no recurrent injuries

Compliance vs. noncompliance – and reinjuries. Eight of the 50 athletes in the study chose to return to play prior to completing all three phases of the rehabilitation protocol (noncompliant athletes) – and half (4) suffered a recurrent hamstring injury. The recurrence rate was significantly lower (P<0.01) for compliant athletes (0%) versus noncompliant athletes (50%).

- Three noncompliant athletes, recreational runners, chose to return to running prior to completion of rehabilitation as they felt they were at low risk of reinjury (one sustained a reinjury).
- A recreational softball player and a high school football player returned to play understanding the increased risk but wanted to complete their competitive seasons (both sustained reinjuries).
- A Gaelic football player had to return to college prior to completing the rehabilitation and did not have the facilities to continue while at college. He sustained a reinjury, and chose not to return to school until completing the rehabilitation.
- One fitness class participant returned prior to completion as her priority was to maintain her fitness routine.
- A high school soccer player went off to college prior to completing rehabilitation and chose not to pursue rehabilitation there.

Conversely, there were zero injury recurrences in the compliant athletes at an average of 23 ±13 months after return to sport (22 more than two years, 11 between one and two years, ten between six months and one year).

The average number of physical therapy treatments was 11 ±7 for the eight noncompliant athletes and 17 ±7 for the compliant athletes (P=0.09). Time from initial treatment to discharge was 11 ±10 weeks for the compliant athletes and 11 ±8 for the noncompliant athletes (P=0.98). Visits per week were 2.4 ±1.4 for compliant athletes and 1.4 ±0.8 for noncompliant athletes (P=0.07)

Hamstring Strength and the Length-Tension Relationship (Angle-Torque)

For all athletes hamstring strength was not different between the involved and noninvolved sides at each angle at the time of return to sport (side effect P=0.35). However, when strength results were compared between compliant and noncompliant athletes, clear differences were apparent.

- Noncompliant athletes had marked weakness on the involved side that was more apparent at longer muscle lengths, while compliant athletes had no apparent hamstring weakness (Compliance x Side x Angle P=0.006).
- Strength deficit for the noncompliant athletes averaged -29.2 ±15.1% across all angles compared with +1 ±20% for compliant athletes.
- More importantly, strength deficits were progressively greater at longer muscle lengths in the noncompliant athletes (Angle effect P<0.001) while the opposite effect was apparent in the compliant athletes (Compliance x Angle P<0.001). In compliant athletes hamstring strength was slightly lower on the involved side at short muscle lengths but slightly higher on the involved side at long muscle lengths (Angle effect P<0.01).

Athletes who did not complete the rehabilitation program had decreased strength that was more apparent in the lengthened state – consistent with the findings of Brockett et al. For the compliant athletes the eccentric training in the lengthened state restored strength throughout the range of motion and provided a small rightward shift in the length-tension curve. The lack of reinjuries in the compliant athletes indicates that the elimination of weakness in the lengthened state is protective.

Conclusion: Lengthened eccentrics may reduce or eliminate recurrent hamstring injuries

Numerous studies have demonstrated that the most important predisposing factor for a hamstring injury is prior history of a hamstring injury. Therefore, the NISMAT team believes physical therapy must take advantage of any advance that promises the potential to correct the conditions of a prior injury that predispose the athlete to reinjury.

Our study showed that rehabilitation with an emphasis on eccentric strength training with the hamstrings in a maximally stretched position restored strength and resulted in zero recurrent injuries at an average of two years after return to play. Athletes who did not perform lengthened state eccentric training returned to sport with significant weakness, particularly at long muscle lengths, and had a high recurrence rate (50%).

We believe this study provides a useful guide to the techniques that can reduce hamstring strain recurrence.

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