The use of MET and specific STT to increase extensibility and ROM of the hamstring muscle group

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1. Abstract

Introduction: In this study the effects of reduced range of motion and muscle extensibility are illustrated by the hamstrings and its effects of lower limb and lumbar mechanics. Reduced hamstring extensibility is often seen in conditions such as patellofemoral syndrome, plantar fasciitis, and lower back pain. Osteopaths often use specific stretch techniques that essentially comprise of muscle energy and soft tissue massage to improve muscle extensibility and joint range of motion (ROM). Although commonly applied together, evidence to support the effectiveness of muscle energy technique (MET) combined with a specific soft tissue technique (muscle stripping) to increase knee joint ROM is rare.

Objective: The aim of this study was to investigate the combined effects of an isometric contraction MET with a muscle stripping soft tissue technique on passive knee extension (PKE).

Design: Repeated measures cross-over design.

Methods: 20 asymptomatic participants (aged 28-52) with a PKE angle of 20 degrees or more were pseudo-randomized to two counterbalanced groups. Group 1 (n=10) received MET and muscle stripping soft tissue and 7 days later received MET only. The same treatments in reverse order were performed on Group 2 (n=10). Measurements for PKE were recorded pre and post-intervention.

Results: A three-way mixed-method multivariate analysis of variance (MANOVA) revealed a significant overall effect of time indicating that all measures improved following the interventions, regardless of the intervention. Greater improvements were seen in PKE (p=0.041) and passive force (p=0.005) with MET combined with soft tissue treatment, than with MET alone in both groups.

***Conclusion*:** This study demonstrated that adding muscle stripping technique to MET improves passive knee ROM more than MET alone, due to an increase in stretch tolerance as measured by changes in passive force.

Key words: Hamstring extensibility, muscle energy technique, passive knee extension, soft tissue massage, range of motion.

2. Contents

3. List of Abbreviations

CI	Confidence interval
CR	Contract-relax
d	Effect size (Cohen's d)
EMG	Electromyography
H-reflex	Hoffman reflex
MANOVA	Multivariate analysis of variance
MET	Muscle energy technique
MS-STT	Muscle Stripping Soft Tissue Technique
MVIC	Maximal voluntary isometric contraction
n	Sample size
PNF	Proprioceptive neuromuscular facilitation
PKE	Passive knee extension
ROM	Range of motion
s	Seconds
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
ST	Soft tissue

Section One: Literature Review

2. Introduction

Adequate range of motion is important for the comfortable completion of activities of daily living (Williams, Odley & Callahan, 2004). When a muscle displays insufficient extensibility and is considered ‘short’ or ‘tight’ the motion between joint surfaces may be reduced, resulting in restricted joint range of motion (ROM) (McCreary et al., 2005). When a muscle shows excessive extensibility, the motion between joint surfaces may be disproportionately larger resulting in excessive joint ROM (McCreary et al., 2005). In both cases, an aberration from optimal extensibility is believed to precipitate abnormal wear patterns on the articular surfaces and capsular structures of the involved joints (Scott K Lynn & Costigan, 2009; McCreary et al., 2005; Weppler & Magnusson, 2010).

The hamstring muscle group is frequently observed to have reduced muscle extensibility (Nagarwal. A.K, Zutshi. K, Ram. C. S, & Zafar. R, 2009) with authors identifying consequent effects on lower limb and lumbar mechanics (Harty et al., 2005; Massoud et al., 2011; White et al., 2009). This review defines muscle extensibility and describes the different components of extensibility. It then explores reduced muscle extensibility in the hamstring muscle group and the effect this has on the lower limb and spine. Finally, it considers the current evidence relating to the efficacy of treatments aimed at improved hamstring extensibility, and its effect on lower limb and spine mechanics and pain.

3. Muscle Extensibility

Muscle extensibility can be defined as the ability of a muscle to extend from a resting position to a predetermined endpoint, in which the joints maximal ROM reflects the muscle’s maximal length (Blackburn, Padua, Riemann, & Guskiewicz, 2004; Gajdosik, 2001; Weppler & Magnusson, 2010). Muscle extensibility is further defined as the ability of skeletal muscle to lengthen without muscle activation (Gajdosik, 2001; Weppler & Magnusson, 2010). It is also the distance that is achieved between an initial muscle length and the maximal muscle length (Gajdosik, 2001). When a muscle is passively stretched from a shortened position, the first point of resistance that is experienced is called initial passive resistance (Chaitow, 2006a; Gajdosik, Rieck, Sullivan, & Wightman, 1993).

Muscle extensibility is one aspect of muscle length, with muscle length said to be directly proportional to the number of sarcomeres in series found within the muscle (Hamill & Knutzen, 2003; Levangie & Norkin, 2005; Weppler & Magnusson, 2010). The muscle- tendon unit, which contains the sarcomeres, is the anatomical and physiological unit responsible for muscle contraction and thus voluntary joint movement (Hamill & Knutzen, 2003). The tendon itself is composed of dense regular connective tissue and is part of the series elastic component of the muscle-tendon unit which has minimal length extensibility properties (Gajdosik, 2001; Hamill & Knutzen, 2003). The muscle belly contributes largely to the overall passive length-tension relationship during muscle stretching (Blackburn et al., 2004; Gajdosik, 2001).

Length tests are used by the clinician to assess excessive or limited muscle extensibility. In a clinical setting it is most common for length tests to demonstrate reduced muscle extensibility or what it synonymously known as muscle tightness or shortness. The latter terms are subjective and are often used interchangeably within literature. Muscle tightness is considered an increase in tension from either active or passive mechanisms. Muscles can actively shorten through spasm or contraction; or passively through postural adaptation and scarring. Irrespective of the presence of active or passive mechanisms, muscle tightness causes a restriction in joint ROM which can create muscle imbalances (Myers, 2001; Phillip Page, Frank, & Lardner, 2010; Ward, 2003). It is important for muscles to achieve sufficient extensibility not only to allow for adequate joint ROM, but also to produce the necessary amount of active and passive tension that is required to stabilize a joint during movement (Weppler & Magnusson, 2010).

4. Reduced Hamstring Extensibility

The effect of reduced muscle extensibility in the hamstring muscles has been extensively researched in literature. It has been reported that reduced hamstring extensibility has a wide range of effects on lower extremity and lumbo-pelvic mechanics. It is believed this is due to the complexity of the hamstring attachments, as it crosses both the hip and knee joints (Schuenke et al., 2006). The hamstring muscle group has its proximal insertion at the ischial tuberosity. Its distal insertions include the medial surface of the tibia at the pes anserine junction, the medial tibial condyle, and the fibular head. Authors believe this complex array of insertions allows decreased extensibility of the hamstrings to contribute to impaired function in the lower limb and lumbo-pelvic region (Gray, 1995; Hamill & Knutzen, 2009). Such impairments are caused when hamstring tension is increased and contribute to altered gait, patellofemoral joint dysfunction, plantar fasciitis and low back pain.

4.1. The influence of hamstring extensibility on gait

It has been proposed that an increase in tension of either medial or lateral hamstrings can alter the rotation patterns of the tibia on the femur and prevent adequate extension during normal gait (Stewart, Jonkers, & Roberts, 2004; Whitehead, Hillman, Richardson, Hazlewood, & Robb, 2007). Altered gait patterns can result in unusual wear patterns on the cartilaginous structures of the knee, and exacerbate anterior or medial knee pain (Elias et al., 2011; Scott K. Lynn, Kajaks, & Costigan, 2008). Substantial reductions in hamstring extensibility are, however, needed before significant changes in gait are apparent (Whitehead et al. 2007). Whitehead et al. (2007) investigated the effect on gait of simulated and isolated hamstring shortening in six healthy females. Whitehead et al. (2007) believe that adequate hamstring length is essential for a normal gait. Although 'adequate' was individual, it was observed that some participants had evident hamstring shortening on physical examination yet minimal changes in gait.

A possible cause for anterior patellar pain and anterio-medial knee pain is reduced hamstring extensibility (Whyte, Moran, Shortt, & Marshall, 2010). Reduced hamstring extensibility causes posterior translation and external rotation of the tibia, changing the angle between the femur and tibia and thus placing a greater amount of stress on the pes anserine junction and patellar (Blackburn et al., 2004; Elias et al., 2011; Kwak et al., 2000). This biomechanical alteration in patella posture contributes to and exacerbates patella-femoral disorders (Hamill & Knutzen, 2009). In support of this premise, several authors have reported that individuals with patellar pain were more likely to have reduced hamstring extensibility than those without pain (Mousavi & Norasteh, 2011; White et al., 2009; Whyte et al., 2010).

It has been hypothesized that reduced hamstring extensibility can shift the patellar laterally, transferring the pressure from the medial cartilage to the lateral cartilage of the patella. This shift can predispose to abnormal wear patterns. This phenomenon is supported by Elias et al. (2011) who found that as hamstring tension increased the patellar reciprocated by flexing and shifting laterally. Elias et al. (2011) concluded that this altered position is associated with an increase in patella-femoral pressure, which can further precipitate abnormal loading and subsequent wearing of the underlying patella cartilage. This finding reflects the deleterious effects of reduced hamstring extensibility on the function of the patellofemoral joint and indicate that any misalignment can cause pain.

4.2. The influence of hamstring extensibility on plantar fasciitis

Plantar fasciitis is a repetitive micro-trauma overload injury that occurs near the proximal attachment of the plantar fascia (Healey & Chen, 2010; Labovitz, Yu, & Kim, 2011). It has been indicated that reduced hamstring extensibility is a possible aetiological factor in the development of plantar fasciitis (Aranda Bolivar, Munuera, & Polo Padillo, 2013; Harty et al., 2005; Labovitz et al., 2011), and can increase the risk of developing plantar fasciitis by 8.7 times (Labovitz, Yu, & Kim, 2011). Harty et al. (2005) explored the possible reasons for the increased risk of plantar fasciitis due to reduced hamstring extensibility. The authors reported that reduced hamstring extensibility limited knee extension, which induced prolonged fore-foot loading pressure during gait, creating prolonged tension in the plantar fascia. The relationship between hamstring and plantar fascia tension was further discussed in a study by Aranda Bolivar et al. (2013) who used the straight leg raise test to measure hamstring muscle tightness in those with and without plantar fasciitis. The authors reported significant differences in straight leg raise ROM between those with plantar fasciitis (56.8°±9.8°) and those in a control group (85.9°±11.5°). It can be assumed that reduced hamstring extensibility creates a functional deficit on the plantar fascia through increased tension and mechanical stress.

4.3. The influence of hamstring extensibility on pelvic tilt and the lumbar spine

Pelvic tilt is defined as the degree to which the position of the pelvis rotates from the horizontal position when observed in the sagittal plane (Congdon, Bohannon, & Tiberio, 2005). A common reference line running from the anterior inferior iliac spine to the posterior superior iliac spine is used to determine the angle of pelvic tilt with a pelvic inclinometer (Rockey, 2008). Given that the hamstring muscles originate at the ischial tuberosity, it appears logical that hamstring tension can influence pelvic tilt during hip flexion (Congdon et al., 2005; Gajdosik, Albert, & Mitman, 1994; Gajdosik, Hatcher, & Whitsell, 1992; Kendall, McCreary, & Provance, 2005; Li, McClure, & Pratt, 1996). Previous theories have suggested that poor hamstring extensibility results in a posterior pelvic posture, which reduces lumbar spine lordosis and consequently effects the mobility of the lumbo-pelvic region (Bridger, Orkin, & Henneberg, 1992; Hamill & Knutzen, 2003; Kendall et al., 2005; Kuchera, 2003; McCreary et al., 2005). Research to support this phenomenon is, however, varied.

4.4. The influence of hamstring extensibility on the patella-femoral joint

The importance of this phenomenon is reflected in manual workers performing lifting tasks, as discussed below. It has been proposed that reduced hamstring extensibility plays a significant role in excessive loading of the spine during manual lifting tasks. In support of this, Carregaro and Gil Coury (2009) reported that individuals with reduced hamstring extensibility are at greater risk of injury as they adopt a more posterior tilted pelvis during manual lifting. The compensatory posterior pelvic tilt creates excessive flexion of the lumbar spine during lifting. The impact of this compensation thus increases the intra-discal pressure and anterior shear forces on the elastic structures of the spine (Alacid, 2010). Thus, increasing the risk of injury (Hamill & Knutzen, 2009).

4.5. The lower crossed syndrome

One of the most clinically significant findings in patients with **non-specific low back pain** is reduced hamstring extensibility (Marshall, Mannion, & Murphy, 2010; Massoud et al., 2011; Nourbakhsh et al., 2006; Nourbakhsh & Massoud, 2002).

While reduced hamstring extensibility is a common finding in patients with low back pain (Wong & Lee, 2004), authors have proposed that this phenomenon is a compensatory mechanism to control excessive lumbar spine lordosis, and is caused by specific patterns of muscle impairments known as ‘pelvic crossed syndrome’ or ‘lower crossed syndrome’ (Kendall et al., 2005; Massoud et al., 2011; Nourbakhsh et al., 2006). This theory proposes that a specific muscle imbalance exists in which tightness and over activity of the hip flexors and low back extensors (postural muscles) coexists with underactive lower abdominal and gluteal (phasic muscles) (Chaitow, 2006b; Nourbakhsh et al., 2006). The imbalance results in anterior pelvic tilt, hyper-lordosis and restriction of the lumbar spine (Chaitow, 2006b; Phillip Page et al., 2010).

The mechanical link between impaired muscle patterns of the lower crossed syndrome is, however, explained by inhibited and weakened gluteal muscles, causing sacroiliac joint dysfunction. This aspect of the lower crossed syndrome is further supported in literature as the gluteus maximus and long head of the biceps femoris are both involved in the stability of the sacroiliac joint as they provide fibres to the sacrotuberous ligament and long dorsal ligaments at the ischial tuberosity (DeRosa & Porterfield, 2007; van Wingerden, Vleeming, Kleinrensink, & Stoeckart, 1997). If the gluteal muscles are weakened, the tension on the ligament is reduced. Consequently, the hamstrings are thought to compensate for this reduced ligament tension by tightening to improve sacroiliac joint stability (Massoud et al., 2011). It is important to note that most of the studies reviewed reported hamstring muscle tightness in individuals with low back pain, yet failed to differentiate between the sources of pain in the lumbar or sacral region. Further research is needed to identify the effects of both muscle impairments (muscle weakness and muscle shortness) collectively as it is difficult to ascertain whether the cause was due to individual patterns of muscle impairments or both. Also, from a clinical perspective, further research is required to study the therapeutic value of strengthening gluteal muscles and lengthening hamstring muscles in patients with low back pain.

5. Stretching and Muscle Extensibility

The previous sections of this literature review have defined muscle extensibility and discussed the effect of reduced hamstring extensibility on mechanics of the lower extremities and the lumbo-pelvic region. The current literature suggests that reduced hamstring extensibility can cause altered gait patterns (Whitehead et al., 2007) and may precede the development of patella-femoral joint dysfunction (Elias et al., 2011; White et al., 2009), plantar fasciitis (Aranda Bolivar et al., 2013; Harty et al., 2005) and low back pain (Massoud et al., 2011; Nourbakhsh et al., 2006).

Manual therapists believe that maximum muscle extensibility is vital for maximum joint ROM and that reduced muscle extensibility can influence functional activities and athletic performance (Sexton & Chambers, 2006; Worrell, Smith, & Winegardner, 1994). There are many therapeutic interventions used by manual therapists that are designed to improve muscle extensibility and joint ROM. Such techniques include static stretching, massage therapy, proprioceptive neuromuscular facilitation (PNF) stretches and muscle energy technique (MET). These techniques are often employed as an important component of physical rehabilitation. To this review both MET and PNF will be classified as contract-relax (CR) techniques due to their underlying similarities, unless clearly stated. Sections 4 through to 6 of this review will focus primarily on the role of static stretching, massage therapy and CR technique in the treatment of reduced muscle extensibility.

5.1. Stretching to improve muscle extensibility

Stretching exercises are frequently utilized and prescribed in manual therapy and are often the **primary focus of rehabilitation** (Phillip Page et al., 2010). The purpose of stretching is to prevent shortening and tightening of muscles. Stretching can also improve functional joint ROM by increasing the elasticity of not only muscles but tendons, fascia, ligaments and the joint capsule (Ylinen, 2008). Stretching to maintain adequate muscle extensibility has been largely advocated in physical rehabilitation as it is required to achieve physical movement and ideal joint postures (Levangie & Norkin, 2005). Individual lifestyles and professions may vary in their physical demands; an individual who is desk bound may not require normal joint ROM, whereas individuals involved in more physically demanding jobs may require greater mobility of their extremities and spine (Carregaro & Gil Coury, 2009; Ylinen, 2008). Moreover, physical hobbies and sports involve greater demands on unilateral muscles due to specific movement patterns (Ylinen, 2008). Increasing joint stiffness and reduced muscle extensibility is becoming more prevalent (Ylinen, 2008). It is, therefore, necessary for individuals to engage in stretching procedures to maintain adequate joint ROM that caters to the demands and physical requirements of their jobs. In a clinical setting, there are several factors which can limit muscle extensibility and joint ROM such as pain, muscle spasm, soft tissue adhesions, contractures and immobilization, all of which can be improved through specific stretching procedures (Arab & Nourbakhsh, 2014; Ylinen, 2008).

5.2. Viscoelastic deformation during static stretching

Many studies have suggested that the immediate increase in joint ROM that is found after stretching is due to viscoelastic deformation (McHugh, Magnusson, Gleim, & Nicholas, 1992; Webright, Randolph, & Perrin, 1997). Mechanical elongation of muscle is thought to be ascribed to the viscoelastic properties of connective tissue. The term ‘viscoelastic’ is coined through the combined effect of viscous and elastic properties of muscle fibres, which undergo changes when a stretch is applied (Leveau, 1992). Muscle displays elasticity which implies that changes in muscle length are directly proportional to the applied force. These elastic properties allow the muscle to return to its original length after a stretch is applied and the tensile force is removed.

Viscoelastic deformation can be observed when a static stretch is applied to a muscle for a period and is expressed as the gradual decline in resistance of the muscle to the stretch. It is difficult to separate these two properties of muscle about the cause of passive resistance to stretching, although it is known that immediately after a passive stretch is performed viscoelastic energy is lost causing a decrease in passive resistance.

5.3. Stretch tolerance change during static stretching

Viscoelastic deformation is evident when the torque required to reach a constant joint ROM is less following a static stretch, or when the torque remains constant yet the joint ROM increases (Ballantyne, Fryer, & McLaughlin, 2003). If the degree of torque is not standardized, the maximum joint ROM achieved may correspond to an individual’s change in perception of discomfort masking any evidence of ‘real’ changes to muscle extensibility (Huang et al., 2010). This mechanism is known as stretch tolerance. Following a static stretch, stretch tolerance occurs when a joint’s ROM increases with an increased torque measurement. This suggests that an individual can apply a greater tensile force to achieve greater extensibility. Similarly, joint ROM measurements can be influenced by individuals if they self-administer a greater stretch torque as their tolerance to stretch rises (Folpp et al., 2006; Magnusson, Simonsen, Aagaard, & Kjaer, 1996). It is, therefore, important to measure torque with joint ROM to discover whether the measured increase in ROM is from viscoelastic change or increased stretch tolerance.

5.4. The effect of stretching on reduced muscle extensibility

Static stretch is often used to improve muscle extensibility and joint ROM (Gajdosik, 1991). Several authors have found evidence to support this notion (Arabaci, 2008; Arazi, Asadi, & Hoseini, 2012; Gajdosik, 1991). Static stretching often consists of slow controlled movement of a joint towards its end range or until a stretch sensation is experienced and is held for up to 60 seconds (Gajdosik, 1991).

The effect of stretching on viscoelastic deformation is minimal, short-lived (Magnusson, Aagaard, & Nielson, 2000; Magnusson, Simonsen, Dyhre-Poulsen, et al., 1996) and has little to no wash-over effect on subsequent stretches performed in sequence (Magnusson et al., 2000). This was further demonstrated by Folpp et al. (2006) who reported that long term increases in muscle extensibility were due to increased tolerance to stretch rather than viscoelastic deformation. Folpp et al. (2006) investigated the effects of a static stretch administered five days a week over a 4-week period. The results indicated that increased muscle extensibility in the hamstrings was due to increased stretch tolerance rather than any long term viscoelastic deformation.

6. SST and Muscle Extensibility

Massage therapy and SST aim to stimulate the proprioceptive receptors of the skin and underlying tissues through touch and pressure (Weerapong, Hume, & Kolt, 2005) and is believed to improve mechanical function of the musculoskeletal system leading to improved joint ROM (Arazi et al., 2012; Hopper et al., 2005; Huang et al., 2010; Rushton & Spencer, 2011; Wiktorsson-Möller, Oberg, Ekstrand, & Gillquist, 1983). It has been proposed to increase the extensibility of soft tissue including muscle, tendon, fascia, the joint capsule and ligaments, by preventing the formation of fibrosis and adhesions (Crosman, Chateauvert, & Weisberg, 1984). The effects of massage therapy and SST are presumably produced by more than one mechanism and it is speculated that it has a wide influence on the body through biomechanical, neurological, and psychological mechanisms. This review will explore the proposed mechanisms, whereby massage improves joint ROM.

6.1. Biomechanical mechanisms of massage therapy

Massage therapy involves the use of biomechanical pressure exerted on deformable muscle tissue for the purpose of improving muscle extensibility and joint ROM. It is said to improve muscle-tendon unit compliance by reducing its active and passive stiffness (Weerapong et al., 2005). Increased muscle-tendon unit compliance is achieved by mobilizing soft tissue and elongating shortened or adhered fibrous connective tissue (Hemmings, 2001; Weerapong et al., 2005).

There is limited literature regarding the effects of massage therapy on improving joint ROM. Crosman et al. (1984) studied the effects of a standardized 9 to 12-minute massage routine to the hamstring muscle group in 34 females aged 18-35. Participants were healthy, asymptomatic individuals and were randomized into a massage group or a control group. Clinical outcome measures were taken pre- and post-treatment and at a 7-day follow-up. Outcome measures of hamstring extensibility were the passive knee extension test and the straight leg raise test.

The intervention comprised a combination of massage techniques including deep effleurage, stretching effleurage, petrissage, and friction. The results showed that those in the intervention group achieved a significant, immediate increase in the straight leg raise test of 10.6° (±8.63°), with a ‘very large’ effect size (Cohen’s d =1) and an increase in passive knee extension of 3.74° (±3.08°). This evidence suggests that massage therapy to the hamstring muscle group can improve immediate muscle extensibility. The addition of torque as an outcome measure would aid in determining whether the observed increase in ROM was due to a change in viscoelastic properties or due to an increase in tolerance to stretch.

Rushton and Spencer (2011) investigated the effects of a dynamic passive knee extension stretch of 45-seconds followed by a 30-second application of a transverse medial glide soft tissue technique over the musculo-tendinous junction of the biceps femoris. The passive knee extension test was performed again following massage. The end-point measurements for pre- and post-intervention passive knee extension tests were taken at a point subjectively determined by the participant. ROM and passive torque were measured. The results from this study showed both an increase in passive knee extension and a decrease in passive resistance as measured by changes in passive torque. They concluded that the increase in ROM was partially explained by a reduction in passive resistance via a viscoelastic stress relaxation response of the musculo-tendinous junction (Rushton and Spencer, 2011).

6.2. Neurological mechanisms of massage therapy and SST

The neurological effects of massage are thought to be caused by stimulation of sensory receptors which can trigger an inhibitory effect on the motor neurons, thus decreasing neuromuscular excitability and reducing muscle tension (Weerapong et al., 2005). The Hoffman reflex (H-reflex) is used to measure neuromuscular excitability and is considered an electrical analogue of the stretch reflex (Weerapong et al., 2005). Few studies have shown the effect of massage on neuromuscular excitability as measured by the changes in the amplitude of the H-reflex. Sullivan, Williams, Seaborne, and Morelli (1991) found that a 4-minute petrissage massage to the triceps surae muscle produced a significant decrease in amplitude of the H-reflex by approximately 50% compared to a control receiving no massage.

The degree of pressure applied during the massage procedure may influence the neuromuscular excitability. Goldberg, Sullivan, and Seaborne (1992) studied the effects of different massage pressures on EMG activity. It has been found that both light and deep massage pressures can produce significant reductions in EMG activity as observed by reduced amplitudes of the H-reflex. However, the deeper massage pressures were found to produce greater reductions in H-reflex amplitude.

7. Muscle Energy Technique (MET)

Osteopaths frequently use specific stretching approaches to enhance muscle tissue extensibility through MET methods. MET is used by practitioners from different health professions and has been advocated in the use of stretching and increasing muscle extensibility, decreasing muscle hyper-tonicity and improving joint ROM (Chaitow, 2006a; Ehrenfeuchter & Sandhouse, 2003). Both PNF and MET stretching have been reported to be more effective than static stretching alone in improving joint ROM (Marek et al., 2005; Weppler & Magnusson, 2010; Yuktasir & Kaya, 2009). MET can be defined as “a form of osteopathic manipulative treatment in which the patient’s muscles are actively used on request, from a precisely controlled position, in a specific direction and against a distinctly executed counterforce” (Ehrenfeuchter & Sandhouse, 2003, pp. 881-907).

The systematic protocol for MET involves identifying a restrictive barrier within the normal range of joint motion, which is then followed by an isometric contraction of the agonist muscle. Subsequently, a passive stretch is applied to the muscle for a short period. This form of MET is also known as isometric CR or post-isometric relaxation (Chaitow, 2006a; Ward, 2003). Other forms of MET include contraction of the antagonist muscle at the first identifiable physiological barrier to motion, which is then followed by a passive stretch to the agonistic muscle. This form of MET is known as agonist CR and uses the principles of reciprocal inhibition (Chaitow, 2006a). For this literature review only isometric CR techniques will be explored.

The physiological mechanisms that create changes in muscle extensibility produced by MET and passive stretching remain largely controversial (Chaitow, 2006a). Viscoelastic deformation has been previously tested in studies using static stretching (McHugh, Magnusson, Gleim, & Nicholas, 1992), CR (Magnusson et al., 1996) and massage (Rushton & Spencer, 2011). However, these studies have concluded that the underlying mechanism of increased muscle extensibility is likely due to altered reflex relaxation and altered tolerance to stretch. Most of the research that is pertinent to MET is derived from research related to PNF stretching due to the close similarities between the two techniques (Fryer, 2006).

7.1. Post-isometric relaxation

It has been proposed by several authors that MET creates muscle relaxation via a neurological reflex immediately after an isometric muscle contraction (Ehrenfeuchter & Sandhouse, 2003; Fryer, 2006; Greenman, 1996). The muscle relaxation that occurs after the isometric contraction has been theorized to cause activation of the Golgi tendon organs, which causes an inhibition of the alpha motor neuron pool (Kuchera & Kuchera, 1993; Ward, 2003). In support of this theory, two key studies have provided evidence that a brief neuromuscular inhibition occurs immediately after isometric muscle contraction. Moore and Kukulka (1991) studied the excitability of the alpha-motor neuron following a sub-maximal isometric contraction of the soleus muscle. The researchers found that myoelectric activity decreased for a period of ten seconds following the contraction and recognized this decrease as presynaptic inhibition causing muscle relaxation.

7.2. Viscoelastic deformation and stretch tolerance during MET technique

MET protocols involve varying degrees of static stretching following a contract-relax technique. As discussed previously static stretching causes a viscoelastic deformation in muscle tissue (McHugh et al., 1992) and an increased tolerance to stretch in participants (Magnusson et al., 1996). Several studies exist that support the theory of increased stretch tolerance as a mechanism of increased joint ROM. In fact, Ballantyne et al. (2003) provided evidence that performing an isometric contraction of 75% of maximal voluntary force, for a total of four repetitions, significantly increased the passive knee extension and marginally increased torque, when the stretch was applied to a pain tolerance threshold.

Ballantyne et al. (2003) found that passive knee extension increased by 2.7°±1.3°. An increase in torque was also demonstrated in the experimental group from pre-intervention measurements of 13.7 ± 3.2Nm to post-intervention measurements of 14.3 ± 3.4Nm ($p=0.047$). This increase in torque is marginally significant and supports the notion that stretch tolerance is a mechanism for increased muscle extensibility as greater force was required to achieve greater end range.

It has been hypothesized in two studies that increased stretch tolerance is a mechanism for are not well understood. However, the concept of altered tolerance to stretching as a mechanism for an increase in muscle extensibility has now gained wider acceptance than the theory of reflex relaxation (Fryer, 2006).

7.3. Gate control theory

Previously, it has been proposed that the 'gate control theory' is one mechanism for altered stretch tolerance and pain perception. The gate control theory relates to a situation where two different types of stimuli such as pain and pressure trigger their respective receptors simultaneously (Fryer, 2006; Melzack & Wall, 1965; Sharman, Cresswell, & Riek, 2006).

During MET procedures a muscle is often stretched beyond its active ROM, which then stimulates the joint mechanoreceptors and proprioceptors, thereby creating an inhibition of the incoming signals of pain at the dorsal horn of the spinal cord. In addition, the force generated during contraction is detected and categorized as noxious stimuli, which immediately activates the Golgi tendon organs to inhibit the force and ensure the prevention of injury. As the MET protocol is repeated, both nociception and inhibition of the Golgi tendon organs are decreased, as the muscles and tendons become accustomed to their newly positioned lengths (Fryer, 2006; Magnusson, Simonsen, Aagaard, Dyhre-Poulsen, et al., 1996; Melzack & Wall, 1965; Sharman et al., 2006).

Evidence to support the mechanisms of altered stretch tolerance behind MET for increasing muscle extensibility is limited. However, it does seem plausible that MET can reduce the pain sensitivity and stretch tolerance of treated muscles during stretching, even though the effects may be psychological. There is currently no research on the psychological effects of MET on increasing muscle extensibility. Future studies are needed to help determine psychological effects of MET and increased muscle extensibility.

8. Contract-Relax Technique on the Hamstring Muscle Group

The previous sections discussed the effect of stretching, massage therapy and MET on muscle extensibility. The next section will outline and discuss the effect of the CR technique applied specifically to the hamstring muscle group and its effect on hamstring extensibility.

8.1. The effect of contract-relax technique on hamstring extensibility

There are numerous studies that have investigated the effect of CR technique on hamstring extensibility that are related to CR MET (Ballantyne et al., 2003; Shadmehr, Hadian, Naiemi, & Jalaie, 2009; Smith & Fryer, 2008; Waseem, Nuhmani, & Ram, 2009) and CR PNF stretching (Feland & Marin, 2004; Feland et al., 2001; Ferber et al., 2002; Yuktasir & Kaya, 2009). These studies use similar protocols, however, subtle differences in each study can be found. These differences can mostly be attributed to variability in contraction durations, force, and the number of repetitions used.

The protocols used in the studies involving CR MET have varied from three to four sub-maximal muscle contract-relax repetitions, whilst the duration of contraction has ranged from 3 to 30 seconds (Ballantyne et al., 2003; Shadmehr et al., 2009; Smith & Fryer, 2008). In comparison, the CR PNF studies used two to five maximum muscle CR repetitions, with the duration ranging from three to ten seconds. Throughout the studies reviewed, contraction forces ranged from 20% to 100% of maximal voluntary isometric contraction (MVIC) force. Hamstring extensibility was measured using active and passive knee extension tests, straight leg raise, and torque.

8.2. The effect of contract-relax techniques on active knee extension

The results of two studies indicate that CR techniques can improve active knee extension ROM (Puentedura et al., 2011; Spernoga, Uhl, Arnold, & Gansneder, 2001). These studies both found comparable results in the mean increase of active knee extension ROM following CR PNF protocols using MVIC force during stretching procedures. Spernoga et al. (2001) investigated the lasting effects of a single CR stretch over a 32-minute period in males (aged 18.8±0.63years) involved in military cadet training. The CR protocol consisted of firstly, a seven second passive stretch phase; secondly, a seven second contraction phase; and lastly, a five second relaxation phase that was followed by a seven second stretch. The results indicated that hamstring extensibility significantly increased by 7.8° (SD not reported; d=0.5) following the intervention, with lasting effects maintained up to 6 minutes. The results from this study however, cannot be generalized to the normal population as this study used males involved in military cadet training, who were involved in high intensity training.

CR techniques have been hypothesized to be more effective than static stretching in improving muscle extensibility (Ferber, Osternig, & Gravelle, 2002). However, research to support this is limited as several studies have found that CR techniques produce comparable gains in joint ROM to static stretching (Feland, Myrer, & Merrill, 2001; Puentedura et al., 2011; Yuktasir & Kaya, 2009). Indeed, this was observed by Puentedura et al. (2011), who used a two intervention cross-over design to compare the immediate effects of a single application of a CR technique to a static stretch over a two week period on a mixed gendered group. The CR intervention consisted of a 10-second contraction phase repeated four times. The static stretch intervention consisted of a 30-second stretch, followed by a 10-second relaxation phase, repeated twice. The results from this study indicated significant mean increases of 8.9° following the CR technique and 9.1° following the static stretch, which is like that found by Spernoga et al. (2001). The results indicated that CR technique and static stretch produce comparable gains in muscle extensibility. A limitation of this study is that the participants' opposite leg was used as a control allowing the participants to become familiarized with testing procedures. This could have influenced the testing results through motivation as the tests were active and therefore dependent on the participants. In addition, this study was found to be underpowered due to the small sample size leading to difficulty in detecting differences between intervention groups. Other studies have, however, found that CR techniques significantly improve active knee extension (Nagarwal. A.K, Zutshi. K, Ram.

C. S, & Zafar. R, 2009; Smith & Fryer, 2008; Waseem et al., 2009). Another possible reason for the undetectable difference in interventions may have been due to a ceiling effect caused by the fact that participants were included in the study when exhibiting minimal restrictions in active knee extension.

The active knee extension test is reliable and arguably safe for assessing knee joint ROM because the end point of available joint ROM is dictated by the participant (Fryer, 2006; Norris & Matthews, 2005). The final position is, however, dependent on the tension developed by the participant's quadriceps muscles and may be influenced by muscle fatigue and participant motivation (Norris & Matthews, 2005), which can cause variability within test results. To control for variable muscle fatigue in participants, both Spernoga et al. (2001) and Puentedura et al. (2011) used a standardized warm-up routine.

8.3. The effect of contract-relax techniques on passive knee extension

At present there is no 'ideal' contraction force for CR as the force used is varied within the literature. Submaximal contractions can produce similar improvements in passive joint ROM according to studies by Ballantyne et al. (2003) and Feland and Marin (2004). Both studies have shown that CR stretch techniques can produce immediate and short term increases in passive knee extension. Ballantyne et al. (2003) found that applying a CR MET using 75% of MVIC force for five seconds followed by a three second rest period, repeated for a total of four cycles was able to produce a significant increase in passive knee extension of 2.7° ± 1.3. Similarly, Feland and Marin (2004) used a contraction duration of six seconds, followed by a longer rest period of ten seconds between contraction cycles, which was repeated three times each day for five consecutive days. However, in contrast to Ballantyne et al. (2003), Feland and Marin (2004) assessed the effectiveness of different contraction forces of 20%, 60% and 100% of MVIC. Their results showed that the use of submaximal contraction intensities of 20% and 60% yield comparable gains in extensibility to 100% of (p=0.002). Therefore, not only are submaximal isometric contraction forces able to produce comparable gains in passive knee extension to maximal isometric contraction forces, they are also safer and more comfortable according to Ferber et al. (2002).

The duration of both contraction and post-isometric stretching phases are varied within literature. Many authors in the field of CR techniques have supported the use of contraction phases lasting between three and seven seconds (Chaitow, 2006b; Ehrenfeuchter & Sandhouse, 2003; Greenman, 1996), whereas authors of previous studies have used durations ranging from five to six seconds (Ballantyne et al., 2003; Feland et al., 2001), and seven to ten seconds (Shadmehr et al., 2009). There is limited research to support the value of longer contraction durations and conflicting results have been shown. It appears that longer contraction durations are more effective in increasing passive joint ROM. This is supported by Feland et al. (2001) who found that a CR technique to the hamstrings with a duration of six seconds, followed by a ten second relaxation period, demonstrated an immediate increase of 5° (SD not reported) in passive knee extension. In comparison, a more recent study by Shadmehr et al. (2009) examined the temporal effects of a slightly longer contraction duration of ten seconds followed by a ten second stretch repeated three times. Passive knee extension increased by 22.1° ± 4.4° over a 4 week period. It may be surmised from this that longer contraction duration provides greater increases in passive knee extension. There does not appear to be any research that has investigated contraction phases longer than 20 seconds on passive knee extension. Further research in this area may add to the knowledge base and find even greater benefits to passive knee ROM.

9. Massage Therapy and Stretching Techniques

Massage therapy, static stretching and CR stretching, when applied alone, have been found to be effective in the treatment of decreased muscle extensibility. Often massage precedes stretching in the clinical setting to firstly allow ‘loosening’ followed by ‘lengthening’ of the muscle. Only one study was found which compared massage therapy with contract-relax stretching (Wiktorsson-Möller, Oberg, Ekstrand, & Gillquist, 1983). Due to this limited evidence, this literature review will also evaluate articles comparing massage therapy with static stretching.

9.1. Massage therapy vs static stretching

It has been found that static stretching is as effective as Swiss massage on improving muscle extensibility. A recent study by Arazi et al. (2012) lends support to this as they compared the effects of a 10-minute Swiss massage technique to a 20-second static stretch repeated three times, each with a 10-second rest interval. The Swiss massage included varying strokes (including effleurage, friction, petrissage, vibration and tapotement) on the anterior and posterior thigh muscles and calf muscles. The static stretch was applied to the plantar flexor, hamstring, hip flexors, hip extensors, hip adductors and hip abductors. The results from this study indicate that Swiss massage is no more effective than static stretch when measured by the sit-and-reach test to assess muscle extensibility.

9.2. Massage therapy combined with dynamic stretching

When massage and stretch techniques are combined, greater increases in muscle extensibility and joint ROM occur (Fritz, 2006). However, very few studies exist that have compared the effect of massage therapy and CR techniques. One study compared the effects of a dynamic soft tissue mobilization technique with a classic massage (effleurage, petrissage and kneading) to the hamstrings muscle (Hopper et al., 2005). The dynamic soft tissue mobilization technique consisted of an eight-minute protocol utilizing both active and passive components of muscle stretching. The therapist located areas of tightness within the muscle and used a fisted hand to apply a massage longitudinally and across the muscle, while the knee was passively extended. This was followed by an active stretch in conjunction with the strokes applied. Finally, an eccentric contraction of the hamstring muscles against the therapist's resistance was performed. The results from this study showed that both techniques produced equally significant and comparable gains in passive knee extension, thus making it difficult to assess whether the improvement was from the active or passive elements of the dynamic soft tissue mobilization.

9.3. Massage therapy vs contract-relax stretching

Adding a stretch technique to a specific massage technique is thought to provide added benefits to muscle extensibility. Previous studies have used varying massage methods yet have not examined the physiological benefits of massage. They have failed to evaluate the different elements of massage such as pressure, time, and speed of the techniques (Hopper et al., 2005). In addition, very few studies have compared stretch to massage. One study by Wiktorsson-Möller et al. (1983) did, however, find that CR stretching was more effective than massage in increasing lower extremity ROM. This study investigated the effect of massage therapy and CR stretching in participants following a warm up session on ROM of the hip, knee and ankle. The massage procedure consisted of a 6-15 minute massage of the entire lower extremity. The stretching procedure used an isometric contraction at maximal joint extension for two seconds followed by an eight second passive stretch. This was repeated five to six times. Wiktorsson-Möller et al. (1983) found that massage significantly improved dorsi-flexion of the ankle by 12%, while other movements of the hip and knee were not significantly improved. Participants in the stretching group demonstrated a significant improvement in all six ranges of motion tested. Wiktorsson-Möller et al. (1983) did not use a CR stretching only group which therefore makes it difficult to assess if the increase in joint ROM came from stretching procedure or the warmup alone. Although this study measured the effects of warm-up, massage and a CR stretch, it did not compare the combined effects of CR stretching with massage, which is still an area of research that is very limited. A major limitation of this study is the small sample size, which consisted of eight participants, making it hard to generalize the findings. A larger sample size may have been able to detect greater changes in ROM following massage.

10. Conclusion

It is often perceived by manual therapists that decreased hamstring extensibility is a limiting factor in ROM of the hip and knee joints. In consequence, this restriction is said to lead to changes in pelvic and lumbar postures which predispose and/or exacerbate low back and lower extremity pain. Muscular tension can occur actively through contraction and muscle spasm and passively, through postural adaptation and scarring. Age and gender can also influence joint ROM.

Several authors have found that hamstring muscle extensibility can be improved through different methods of treatment including CR techniques, such as PNF and MET, and massage techniques. Most of these studies have, however, used varying methods and treatment approaches in the application of both stretch and massage. The time, duration, and massage stroke types differed in each study and making it difficult to assess which technique is the most efficient. The MET studies have used similar protocols, yet the studies relating to massage therapy have used multiple stroke types as used in Swedish style massage, or solely friction massage at the musculo-tendinous junction. To the author's knowledge no study has been performed using a specific massage stroke (such as muscle stripping) to the entire hamstrings muscle group followed immediately by a MET.

Therefore, the aim of this experimental study reported in Section 2 of this thesis is to investigate the effects of an application of a SST combined with MET on knee extension ROM, and compare it to MET used alone. The information gathered from this study will help guide osteopaths in using the most effective methods available to improve muscle extensibility.

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Section Two: The Study Manuscript

1. Abstract

Introduction: In this study the effects of reduced range of motion and muscle extensibility are illustrated by the hamstrings and its effects of lower limb and lumbar mechanics. Reduced hamstring extensibility is often seen in conditions such as patellofemoral syndrome, plantar fasciitis, and lower back pain. Osteopaths often use specific stretch techniques that essentially comprise of muscle energy and soft tissue massage to improve muscle extensibility and joint range of motion (ROM). Although commonly applied together, evidence to support the effectiveness of muscle energy technique (MET) combined with a specific soft tissue technique (muscle stripping) to increase knee joint ROM is rare.

Objective: The aim of this study was to investigate the combined effects of an isometric contraction MET with a muscle stripping soft tissue technique on passive knee extension (PKE).

Design: Repeated measures cross-over design.

Methods: 20 asymptomatic participants (aged 28-52) with a PKE angle of 20 degrees or more were pseudo-randomized to two counterbalanced groups. Group 1 (n=10) received MET and muscle stripping soft tissue and 7 days later received MET only. The same treatments in reverse order were performed on Group 2 (n=10). Measurements for PKE were recorded pre and post-intervention.

Results: A three-way mixed-method multivariate analysis of variance (MANOVA) revealed a significant overall effect of time indicating that all measures improved following the interventions, regardless of the intervention. Greater improvements were seen in PKE (p=0.041) and passive force (p=0.005) with MET combined with soft tissue treatment, than with MET alone in both groups.

***Conclusion*:** This study demonstrated that adding muscle stripping technique to MET improves passive knee ROM more than MET alone, due to an increase in stretch tolerance as measured by changes in passive force.

Key words: Hamstring extensibility, muscle energy technique, passive knee extension, soft tissue massage, range of motion.

2. Introduction

Reduced muscle extensibility is an area that concerns every manual therapist due to the functional restrictions it places on joint range of movement.[1] Muscle extensibility is defined as the ability of a muscle to lengthen from a resting state to a predetermined endpoint, in which the joint's maximum range of motion reflects the muscles maximum length.[2-4] The current literature supports the premise that optimal muscle extensibility is necessary to achieve maximum joint range of motion. It has been reported that an aberration in optimal extensibility can precipitate abnormal wear patterns on articular surfaces and capsular structures of the involved joints.[1,4,5] The hamstring muscle group in particular has been frequently observed to have reduced muscle extensibility, and has been reported to contribute to altered lower limb and lumbo-pelvic mechanics.[6] These changes include altered gait,[7,8] patellofemoral joint dysfunction,[9-12] plantar fasciitis[13-15] and low back pain.[16-19] It is, therefore, a common goal of manual therapists to improve muscle extensibility in the hamstrings to minimize the functional deficit it applies to joint range of motion.

Muscle extensibility is commonly treated through manual therapy techniques. Manual therapists, including osteopaths, use various techniques to improve muscle extensibility such as stretching,[20,21] massage, [22-24] and contract-relax (CR) stretching which includes both MET, [25-28] and proprioceptive neuromuscular facilitation (PNF).[29-32] These techniques, used individually, have been reported to increase muscle extensibility and successfully increase joint range of motion, decrease viscoelastic resistance, and improve tolerance to stretch.

CR techniques, such as MET and PNF, actively engage an individual's muscle upon request, from a position predetermined by the practitioner against a specific counterforce.[33] CR technique has been advocated for the treatment of reduced muscle extensibility.[34] It seems that CR technique is effective in improving muscle extensibility, however current literature contains varying protocols for the implementation of the intervention. The protocols include different contraction forces,[25,27-29] contraction durations,[25,30,33,35,36] and post-contraction stretch duration.[25,26,29] There is clear evidence to suggest that sub-maximal contraction forces are as effective as maximal contraction forces in improving passive range of motion.[25,29] Authors have supported the use of contraction durations ranging from three to seven seconds,[25,30,33,35,36] and there is some evidence to suggest greater improvements in muscle extensibility are gained with longer contract durations of up to ten seconds.[26] Although varying post-isometric stretch durations have been advocated, [25,26,29] there seems so be no ‘ideal’ as durations ranging from 5 to 30 seconds have been reported to produce similar improvements in muscle extensibility.[27]

It is well established that both massage therapy,[23,24,37] and stretch techniques,[26,30,32 12,49,64] are effective in improving muscle extensibility, with both demonstrating similar effectiveness when applied individually.[37] There is evidence to suggest that adding a CR protocol to a static stretch intervention provides significantly greater increases in muscle extensibility over massage alone.[38] The application of a single technique does not, however, reflect clinical practice as manual therapists often use soft tissue massage techniques (STT) followed by a stretch to enhance muscle extensibility. The combination of massage with CR stretch can achieve further increases in muscle extensibility over each technique used individually,[39] however; there are scares evidence to support this premise. Therefore, the purpose of this study is to investigate the immediate effect of a CR muscle energy technique used with and without a specific (muscle stripping) massage technique on clinical measures of hamstring muscle extensibility in asymptomatic individuals.

3. Methods

3.1. Design

A repeated measurement cross-over design was conducted to measure the combined effect of a muscle stripping STT and a MET compared with the MET alone on hamstring extensibility (Figure 1.) The study was performed at the "The Power of Touch" practice, Toronto, Canada.

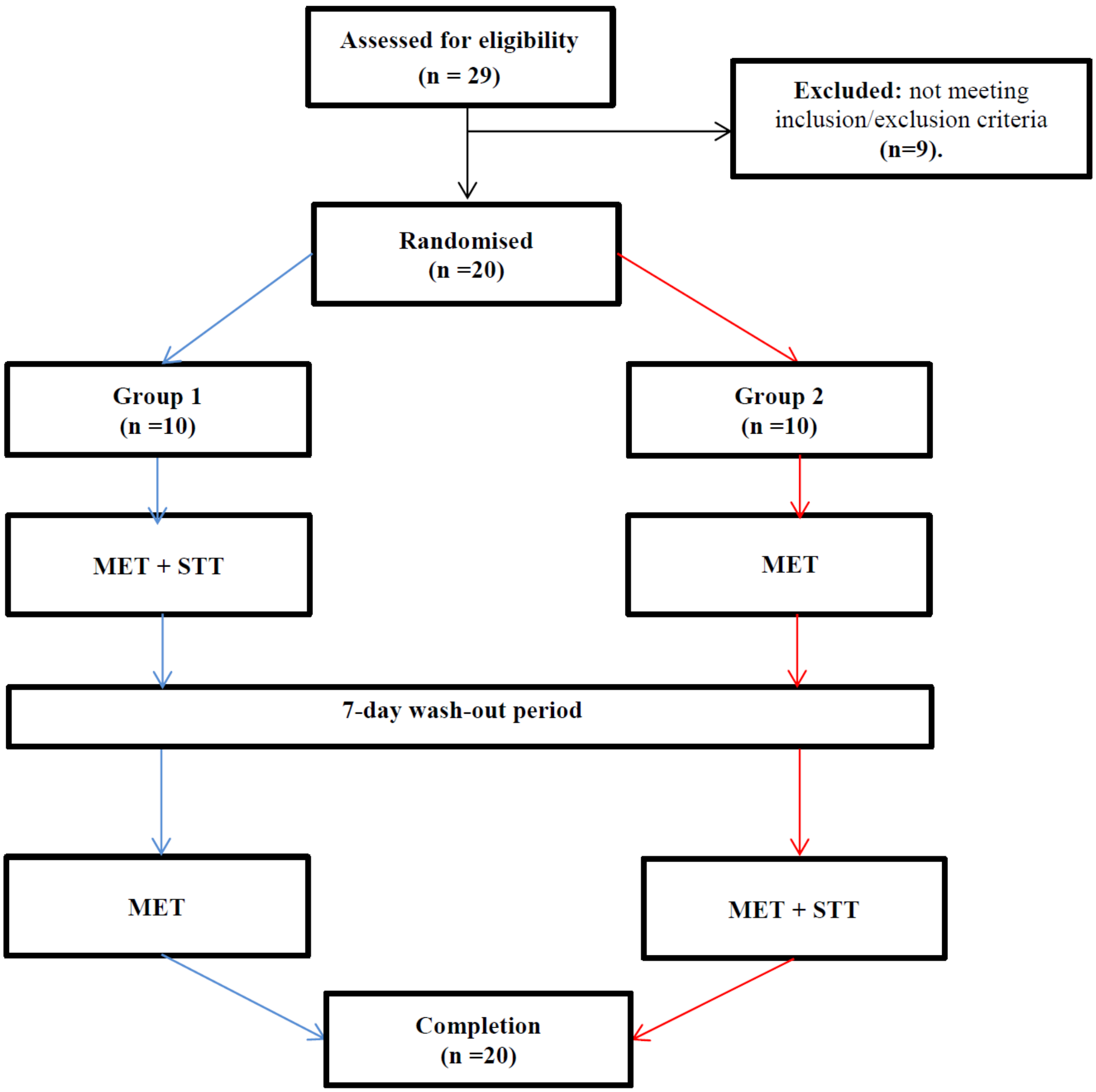


Figure 1. Consort diagram of the study design. Abbreviations: MET = Muscle Energy Technique, STT = Soft Tissue Technique. Key: Group 1 ——— Group 2 ———

3.2. Recruitment

Participants were recruited in my Clinique by verbal invitation and flyers. Individuals that applied for the study were asked to attend an appointment at the clinic to assess their eligibility. Each participant gave written and informed consent prior to eligibility screening and enrolment.

3.3. Eligibility

Assessment for eligibility followed a stringent inclusion and exclusion criteria. The inclusion criteria were healthy adult males aged 28-52 who exhibited a positive passive knee extension test (i.e. angle less than 20 degrees from full knee extension). Participants were excluded if they: a) had any current or recent injuries within the last 6 months to the lower extremities, hip or spine; b) were currently receiving manual therapy or treatment to the lower extremities; or c) had a known musculoskeletal, neurological, vascular, lymphatic disorder.

Participants were asked to refrain from taking any over-the-counter medications that may affect the musculoskeletal system such as muscle relaxants or analgesics, avoid strenuous exercise, and minimize any heavy physical activity two days before and at the day of data collection. Participants who were considered eligible for the study were given an information sheet outlining the requirements of participation and were given the opportunity to discuss all protocols with the lead researcher.

3.4. Instrumentation

The room was arranged with one adjustable (electric) treatment table and a video camera (Canon PowerShot) that was positioned two meters perpendicular to, and level with, the centre of the treatment table. The positions of both table and tripod were measured and marked on the floor with tape to ensure consistency of the positions between the two sessions.

A support surface was created to fit over the table (Figure 2.) The support surface was designed to secure the participants limbs (one secured at 90-degree hip flexion, the other secured in a neutral position) and prevent excessive movement during testing procedures.

Straps were used to prevent further hip flexion during knee extension testing procedures. The contralateral limb was securely strapped down to the table. to prevent excessive hip and pelvic rotations during testing procedures.[40] For both tests, the participant's head was kept in a neutral position to avoid any neural tension that may occur which can cause a limitation in knee ROM and extensibility of the hamstring muscle.[41]

With the participant supine, bony landmarks were easily identified and marked with a circular adhesive label to provide reference points to measure the degree of knee extension. The landmarks used consisted of the greater trochanter of the femur, lateral femoral condyle and lateral malleolus.

3.5. Procedure

Once accepted into the study the participants were randomly assigned to one of two groups using a pseudo-random sequence generator (www.random.org). All participants underwent both intervention procedures: MET and MET combined with soft tissue massage (MET + STT) (Figure 1). Each participant received both intervention protocols separated by seven days at approximately the same time of day. Outcome measures were taken immediately prior to and following the intervention. Participants were instructed to refrain from strenuous exercise and stretching their hamstrings two days prior to the first testing session and during the 7-day interval between trial dates. The participants allocated to group 1 received MET alone in the first week follow by MET combined with muscle stripping massage in the second week. Participants in group 2 received the interventions in the reverse order to group 1. The order of techniques followed normal clinical practice in which muscle stripping massage technique was performed, followed by MET.

3.6. Outcome Measures

The extensibility of the hamstring muscles was assessed using the passive knee extension (PKE) tests. A hand-held dynamometer was used during the PKE test to accurately record the force required to extend the participants knee.

The PKE test is another orthopedic test that is often used to measure knee joint range of motion and hamstring extensibility.[48] The operator firmly held the calcaneus and maintained the foot in a neutral foot position and then slowly (approx. 10°/s) extended the knee joint until the end range of knee extension was identified by the participant requesting to stop. The participants were all instructed to allow the knee to "extend to the point where they could go no further". Additionally, a hand-held dynamometer (Chatillon Model MSE 100) was placed on the posterior calcaneus and used to determine the force used to reach end- range during the PKE test. Again, the average of three repetitions was used for analysis. Digital photography and computer analysis was used to determine the changes in ROM at the knee joint. All measurements of hamstring extensibility were reported as degrees from full knee extension (Figure 2).

The PKE has been reported to be a reliable test for detecting changes in passive hamstring tension,[30,44,48] and has been commonly used in several studies investigating reduced hamstring extensibility.[25,29-31] The use of a hand-held dynamometer to detect changes in passive resistance has also been found to have high reliability,[49,50] and is used to aid with the understanding of biomechanical change and altered tolerance to stretch.[23,25]

3.7. Intervention

Participants remained fixed to the support surface for the duration of the measures and intervention, with the right lower limb being used for all participants. All techniques were performed by the researcher who is a Doctor of Osteopathic student, Registered Massage Therapist and holds DOMP.

Muscle Energy Technique

The MET intervention used for this study was based on the method described by Chaitow (2006a), Greenman (1996) and Ehrenfeuchter and Sandhouse (2003) and was clearly explained to each participant immediately before each session.[33,34,36] Participants were instructed to not extend their right hip while flexing their knee joint. The final instruction given to each participant was to indicate if at any point during the procedure they experienced pain or discomfort, which would be a sign for the procedure to be stopped immediately.

The MET intervention proceeded as follows: a) the practitioner placed their left hand above the knee joint to provide stability, whilst the right hand was positioned above the posterior part of the calcaneus; b) slowly, the practitioner extended the knee joint until the first restriction barrier to stretch was perceived by the practitioner; c) the participant was asked to contract their hamstring muscle by “gently but firmly pushing their heel of their right foot down towards the table, using approximately 20% of their perceived strength”,[35] the contraction phase was maintained for a period of seven seconds against the resistance provided by the practitioner as recommended by Greenman (1996); d) the participant was then instructed to “relax” the hamstring muscle.[36] The post isometric relaxation phase was approximately another 7 seconds to allow the participant to completely relax before the next step; g) the practitioner repeated from step b) for a total for three contraction phases.

The soft tissue muscle stripping intervention combined with muscle energy technique

The soft tissue muscle stripping intervention consisted of a five-minute application of soft tissue massage to the hamstrings muscle group of the right leg followed by the MET as described above. The order in which technique was applied first follows normal clinical practice.[39] The massage technique used in this study was a specific STT in which the pressure is applied along the muscle fibers from origin of the muscle to its insertion. This is done slowly at the beginning of treatment. Pressure will increase with each compression - within client's pain tolerance. The muscle stripping technique can be performed using the fingertips, the ulnar border of the hand, the thumb or the elbow, but for consistency of the study - only the use of the Ulnar border was utilized.

The STT intervention used in this study is as follows: a) the participant was placed in the prone position on the treatment table; b) After locating the biceps femoris part of the hamstrings muscle group, the practitioner used the Ulnar border of their right arm to apply the muscle stripping technique; c) after 2.5 minutes, the practitioner then performed the muscle stripping technique on the semimembranosus and semitendinosus portions of the hamstrings for the remaining 2.5 minutes. After the STT was performed, the participant was asked to change to a supine position in order for the MET protocol described above to be performed.[33] Finally, the participant was then asked to reposition themselves on the support surface and prepare for post-intervention measurements.

3.8. Data Extraction

The experimental trials were photographed using a digital camera (Canon PowerShot) and were later transferred to a computer for analysis of the knee extension angles. The angles of PKE were measured using standard Baseline Hi-Res Plastic 6' Goniometer while the participant was in the supine flexed hip and extended knee position immediately before and after the intervention.[51] The mean values of the three measurements were used for data analysis.

3.9. Statistical Analysis

Statistical analysis of the experimental data was performed with a three-way mixed method multivariate analysis of variance (MANOVA) using the SPSS v.20 64bit edition software for Windows® 10.[52] The MANOVA was used to allow several dependent variables to be compared simultaneously with several independent variables and the possible interactions between independent variables. A between-group contrast was also performed to explore between-group differences. The MANOVA method was considered appropriate for this study as it was a repeated measures design and allowed for the comparison of the effects between MET alone and MET combined with STT interventions with the three outcome measures of PKE and force.

Throughout the text all data is reported as mean (SD), and significance is set at the $p<0.05$.

4. Results

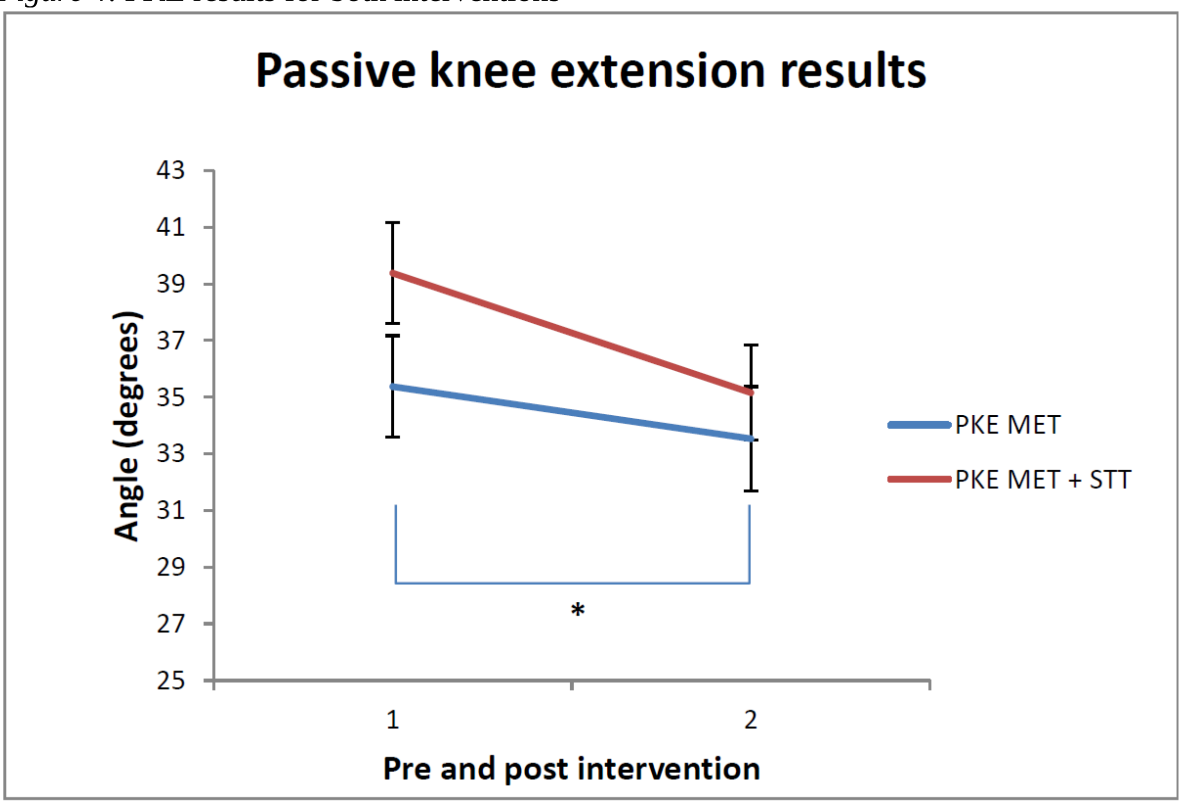
The study sample consisted of 20 male participants randomly allocated to either group 1 (n=10) or group 2 (n=10). The mean age of participants was 28 (±5.6), the mean weight of participants was 78.6kg (±9.5) and the mean height of participants was 178cm (±8.1). Paired *t*-tests indicated there was no significant difference between the groups for height ($p=0.57$) and weight ($p=0.28$), however, there was a significant difference in age ($p=0.03$).

A significant overall effect of time (pre intervention and immediately afterwards) was observed (Wilks $\lambda = 0.296$, F (3, 16) = 12.69, $p<0.001$, partial eta squared = 0.704, and power to detect effect = 0.997). Significant univariate main effects were obtained for PKE (F (1, 183.7) = 28.65, $p<0.001$, partial eta squared = 0.614, and power to detect effect was .99) and Force (F (1, 265.84) = 12.09, *p*=0.003, partial eta squared = 0.402, and power to the detect effect was 0.908). Indicating that all measures improved following the interventions, regardless of the intervention.

A significant interaction was found between intervention and time (Wilks λ = 0.556, F (3, 16) = 4.26, p =0.02, partial eta squared = 0.444, and power to detect effect = 0.761).

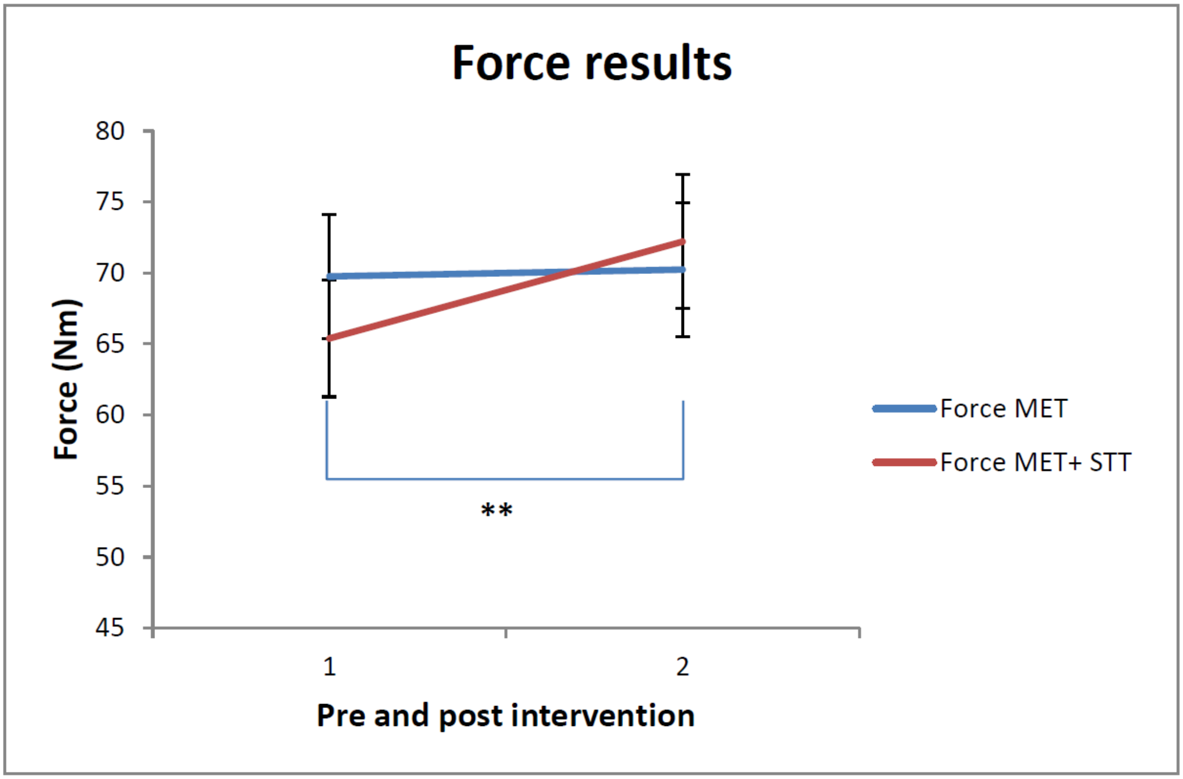
There was a significant effect for PKE (F (1, 28.195) = 4.87, p = 0.041, partial eta squared = 0.213, power to detect the effect was 0.551) (Figure 4), and Force (F (1, 202.14) = 10.41, p = 0.005, partial eta squared = 0.367, power to detect the effect was 0.862) (Figure 5). **Results indicate greater improvements in PKE and force with the MET combined with STT group, compared with the MET alone group.** A moderate negative correlation was found for PKE and force for MET alone, r = -0.488, n = 20, p=0.029, however a significant correlation of these variables was not observed for the MET combined with STT group (r = 0.152, n =20, p =0.523).

Figure 4: PKE results for both interventions



Note: ***** indicates significance at the *p*=<0.05 level

Figure 5: Force results during PKE test for both interventions



Note: indicates significance at the p=<0.01

4.1. Internal Validity

Multivariate analysis revealed a significant interaction between group (order allocation) and intervention (Wilks λ =0.512, *F* (3, 16) = 5.08, *p*=0.012, partial eta squared =0.488. Power to detect the effect was 0.837). Univariate analysis indicated that this interaction was owing to a group by intervention effect for force only (*F* (1, 2831) =12.65, *p*= 0.002, partial eta squared=0.413, and power to detect the effect was 0.919). Significant interactions were not found for variables of PKE, (*F* (1, 52.12) =1, *p* =0.330, partial eta squared =0.053, and power to detect effect =0.15

5. Discussion

5.1. Overview

The aim of this study was to document the immediate effect of a MET combined with a specific STT on clinical measures of hamstring muscle extensibility in asymptomatic individuals. This study also sought to investigate the MET used in isolation. Whilst CR technique and massage therapy have been reported to independently improve muscle extensibility, as measured by passive knee ROM and force, there is no evidence that demonstrates the effectiveness of a specific STT combined with MET. The results of the current study indicate that MET combined with specific (muscle stripping) STT to the hamstring group is associated with significant increases in PKE due to increased stretch tolerance. Significant increases in hamstring muscle extensibility were demonstrated in those receiving the MET alone and were attributed to mechanical deformation. This is an important finding and implies that while soft tissue massage combined with contract-relax muscle energy technique is more effective than the muscle energy technique alone, the combination of techniques also creates viscoelastic deformation alongside altered stretch tolerance.

5.2. Contract-relax technique

The immediate increases in hamstring extensibility following MET technique observed in this study are consistent with the current evidence that CR stretching improves PKE in asymptomatic individuals.[25,29,30,53] The current literature contains a wide range of CR protocols including different contraction forces, duration of contraction, and duration of post-isometric stretch. The CR stretch protocol of the current study was based on recommendations by Greenman (1996), yet there is little evidence to support these recommendations and it remains somewhat unclear which is the most beneficial protocol for CR stretching.[36]

5.3. Muscle contraction force

Submaximal contraction forces are recommended for safety reasons to minimize risk of contraction induced injury.[29] The findings of the current study supports the evidence that submaximal contraction forces are associated with increased muscle extensibility.[25,27,29] Feland and Marin (2004) concluded that submaximal contraction forces of 20% and 60% of maximum force were as effective as maximal contraction forces for increasing muscle extensibility.[29] The current study did not compare the effectiveness of varied contraction forces on muscle extensibility yet the findings do suggest that a submaximal contraction force of 20% may be sufficient.

5.4. Muscle contraction duration

It appears that muscle contraction produces a brief depression of myoelectric activity possibly through the inhibition of the Golgi tendon organs, thereby allowing greater muscle extensibility.[56,57] The findings of the current study suggest that a muscle contraction of seven seconds, as recommended by Greenman, 1996) is effective in increasing hamstring muscle extensibility.[36] This is in concordance with authors who have used similar contraction durations ranging from three to seven seconds and with contraction duration of 10- seconds.[6,25,29,30,46,53] Unlike evidence for muscle contraction force there is a lack of literature comparing the effectiveness of different contraction durations. It may be supposed that a longer contraction time allows for greater inhibition of Golgi tendon organs, allowing for further increases in muscle extensibility, however, further research is required to compare different contraction durations for the purpose of identifying the 'ideal' duration.

5.5. Post-isometric stretch duration

The present study used a short post-isometric stretch of between three and seven seconds as advocated by Greenman (1996), which is consistent with protocols used in currently published literature.[6,25,31] It is unclear which duration is most effective. Smith and Fryer (2008) compared post-isometric contraction stretch durations of three and 30-seconds.[27] The authors concluded that both stretch durations were equally effective in improving hamstring extensibility however only active hamstring extensibility was measured. Post-isometric contract stretch durations of 30-seconds or more may have a larger effect on passive hamstring extensibility through greater viscoelastic deformation and tolerance to stretch. There is no evidence to support this however. Further research comparing stretch duration on active and passive muscle extensibility is needed as it is difficult to determine which post- isometric stretch protocol is most effective, and which mechanism is being altered.

5.6. Massage therapy and stretching techniques

Increased muscle extensibility has been observed following CR stretching,[25-27,29,30] and massage therapy,[22,23,37,56] with a greater increase being observed following a CR stretch than massage therapy.[38] Both CR and massage therapy share the similarity of viscoelastic deformation as an underlying mechanism for improving muscle extensibility.[23,57]

The current study appears to be the only one measuring the effect of CR stretch combined with STT and suggests that combining a CR stretch with STT achieves greater increases in passive hamstring extensibility than CR stretch alone. The degree to which soft tissue massage contributed to the improved muscle extensibility is unclear. Several studies investigating massage alone have shown confounding results due to variations in massage stroke type, duration, and location of applied massage.[22-24,37,38,56] The present study suggests that the combined effects of muscle stripping STT and MET produce both viscoelastic deformations alongside altered stretch tolerance.

The present study used a five-minute muscle stripping soft tissue massage technique on the hamstrings for improving passive extensibility but found similar results to studies that used varying durations from 10 to 30 seconds,[23,24] and 9 to 12 minutes.[22,38] Although these studies found significant improvements in muscle extensibility, the stroke types and location in which the massage was applied varied between studies. Many used all stroke types involved in Swiss massage over the entire muscle.[22,37,56] Other studies used a friction type massage over the musculotendinous junction only.[23,24] While the present study used a muscle stripping STT Technique, it still remains unclear which duration, stroke type and location massage produces the greatest improvements in muscle extensibility.

5.7. Physiological mechanisms of muscle extensibility

The findings of the present study demonstrate increased PKE following MET with and without STT. This study supports the current evidence for increased tolerance to stretch as a mechanism of increased muscle extensibility as PKE increased with the presence of increased passive torque.[25,61] Interestingly, this was only found in the combined intervention group.

When MET was used alone an increase in PKE was found without significant changes in force, indicating a biomechanical viscoelastic deformation. Although some studies have found viscoelastic deformation as a mechanism for increased muscle extensibility, it was not expected in the present study as altered stretch tolerance has recently become more accepted than viscoelastic change.[4,61] A possible reason for these conflicting results may be due to non-standardized torque measurements during PKE tests. This study ensured that the same pre-test measurement for torque and joint angle were measured following the intervention to evaluate viscoelastic change in its first post-test measurement or altered stretch tolerance in successive test trials

The increase in passive ROM could be explained by increased compliance or reduced muscle stiffness due to the massage technique employed. The increase in muscle extensibility following STT combined with MET can be attributed to elongation and mobilization of shortened and adhered connective tissue as stated by Huang et al. (2010).[23] Huang et al. (2010) measured the effect of a short duration massage at the musculotendinous junction and found that passive straight leg raise test results were improved significantly due to increased stretch tolerance.[23] However, compared to our study the soft tissue muscle stripping was applied to the entire muscle belly as it contributes largely to the overall passive length-tension relationship during muscle stretching.[2,3] Furthermore, the passive tension of muscle is dependent on structural properties of muscle such as the surrounding fascia, tendons, ligaments and joint capsules.[62,63] The precise degree to which these can elements can be altered by stretch and massage is unknown.

5.8. Internal validity

A limitation of this study was that the lead researcher carried out eligibility assessment, the administration of the intervention, and collected relevant date. Although the use of single researching practitioner introduces bias the design of the study is representative of clinical practice, in which osteopaths assess active and passive range of motion and then implement a treatment strategy. The use of a blinded assessor independent from the lead researcher would strengthen the internal validity of the study.

Furthermore, other studies have found that the end range achieved with PKE is reliant on the tester and depends on the amount of force used to achieve maximal joint ROM.[48] The use of a hand held dynamometer proved difficult to control the speed during passive knee extension. If incorrectly used, excessive speed can induce a stretch-reflex which can limit further passive knee extension and create altered measures of force as found by Gnat et al. (2010).[48]

5.9. External validity

The technique protocol used in this study was analogous to how muscle stripping and muscle-energy techniques are applied in a clinical setting. However, the present study used only asymptomatic males that were aged 28-52 years who exhibited a restriction in hamstring extensibility. It is therefore not representative of patients presenting to an osteopathic clinic. The findings of this study may be generalized only to those patients who have a similar clinical presentation.

5.10. Future Research

This study supports the current evidence for STT combined with MET on short term increases in muscle extensibility. There is, however, limited evidence for the long term effect of STT or CR technique on joint range of motion.

Future research investigating the long term effects and the underlying mechanisms of change would add to the base knowledge on improving muscle extensibility and its effect on viscoelastic deformation, stretch tolerance and increases in muscle length through increased numbers of sarcomeres.

The present study has shown the immediate effectiveness of muscle stripping STT combined with MET in improving muscle extensibility in asymptomatic populations. Future research may look to investigate the long term benefits of such techniques on hamstring extensibility in those who suffer from low back pain, patellofemoral joint dysfunction and plantar fasciitis.

6. Conclusion

The present study documented the immediate effect of a specific (muscle stripping) STT combined with a contract-relax MET on reduced hamstring extensibility. It found that a single application of muscle stripping massage combined with muscle energy technique produced significant immediate effects in passive knee extension through both mechanical and stretch tolerance change. While the effects of these techniques were documented in asymptomatic individuals, such techniques may be beneficial to those who display reduced muscle extensibility in conditions such as low back pain, patellofemoral disorders, and plantar fasciitis.

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