Comparisions of effects of temporomendibular joint stretching technique and suboccipital muscle inhibition technique on hamstring flexibility in indivisuals with short hamstring syndrome

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1. Abstract

Introduction: Modern individuals often maintain incorrect postures for long periods due to excessive use of smartphones and computers, which leads to musculoskeletal dysfunctions and imbalances due to abnormal movements and repetitive patterns. Specifically, the shortening of the hamstring is related to the decrease in muscle flexibility, which can cause various problems such as lower back pain, increased posterior pelvic tilt, and decreased lumbar lordosis. Previous studies have reported that muscle relaxants, physical therapy, nerve mobilization techniques, static stretching, and proprioceptive neuromuscular facilitation (PNF) techniques are effective in increasing hamstring flexibility. However, there are ongoing debates about the sustainability of the treatment effects and recurrence rates, indicating a need for further research on effective intervention methods. Additionally, although the effects of temporomandibular joint stretching techniques and suboccipital release techniques have been reported to improve short hamstring syndrome caused by shortened hamstrings, there has been no research comparing the effects of these two interventions.

Objective: This study aimed to investigate the effects of temporomandibular joint stretching techniques and suboccipital release techniques on the flexibility of the hamstrings in men with short hamstring syndrome over an 8-week period.

Design: This study was designed as a single-blind, randomized, controlled trial.

Methods: Forty-eight adult men with short hamstring syndrome participated in this study. Using block randomization, participants were assigned to one of three groups: temporomandibular joint stretching technique group (TMJ; n = 16), suboccipital muscle inhibition technique group (SMI; n = 16), and a group receiving both interventions (TMJ+SMI; n = 16). The TMJ group performed the technique three times for 10 seconds each, twice a week for 8 weeks. The SMI group conducted the technique once for 2 minutes, twice a week over the same period, while the TMJ+SMI group received both interventions concurrently. Hamstring flexibility was primarily measured before and after the intervention using the straight leg raise test. Secondary measurements included the forward flexion distance test and the popliteal angle test.

Results: The straight leg raise test showed a significant interaction over time between groups ($p < 0.001$). Post-hoc analysis revealed that the TMJ+SMI group demonstrated significant improvements in flexibility compared to the TMJ group ($p = 0.013$) and the SMI group ($p = 0.011$). The forward flexion distance test also showed significant interactions over time between groups ($p = 0.008$). Post-hoc results indicated that the TMJ+SMI group had significant improvements in flexibility compared to the TMJ group ($p = 0.011$) and the SMI group ($p = 0.012$). The popliteal angle test results also revealed significant interactions between time and groups among the TMJ, SMI, and TMJ+SMI groups ($p < 0.001$).

Conclusion: This study confirmed the significant effects of temporomandibular joint stretching techniques and suboccipital muscle inhibition techniques on the flexibility of the hamstrings in men with short hamstring syndrome. Based on these findings, it is recommended to utilize the combined interventions of temporomandibular joint stretching and suboccipital muscle inhibition techniques in adult men with short hamstring syndrome.

Key words: Short hamstring syndrome, temporomandibular joint stretching technique, suboccipital muscle inhibition technique, straight leg raise test, forward flexion distance test, popliteal angle test.

2. Contents

3. Introduction

3.1. Background

Modern individuals often maintain incorrect postures for prolonged periods due to excessive use of smartphones and computers. Such abnormal movements and repetitive patterns disrupt the body's axis and balance, resulting in musculoskeletal dysfunctions and imbalances such as limited movement and reduced flexibility (Ardahan & Simsek, 2016; Holzgreve et al., 2018; Piranveyseh et al., 2016; Van Eerd et al., 2016). Decreased muscle flexibility not only reduces functional capabilities but can also lead to musculoskeletal injuries (Bandy & Sanders, 2001; Halbertsma et al., 1999; Hartig & Henderson, 1999; Hreljac et al., 2000). Such injuries often occur in multi-joint muscles that are highly involved in functional movements and contain a high proportion of fast-twitch fibers, with the hamstring being the most frequently injured multi-joint muscle in the body (Safran et al., 1989). One of the injuries that can occur due to decreased flexibility is hamstring shortening, which can cause lower back pain. Hamstring shortening increases stress on the lumbar spine, increases posterior pelvic tilt, and reduces lumbar lordosis, contributing to flat back syndrome, which can cause back pain (Halbertsma et al., 2001; Valenza et al., 2015; Radwan et al., 2015). It can also limit hip and knee extension and flexion, restricting a person's ability to walk and run, and increasing compressive forces between the patella and femur, potentially causing knee pain (Gajdosik, 1991; Li et al., 1996; Jagtap & Mandale, 2015). Objective assessment tools for evaluating hamstring shortening include the straight leg raise test (SLR), forward flexion distance test (FFD), and popliteal angle test (PA) (Göeken, 1993; Aparicio et al., 2009). Among these, the SLR test is the most representative, and a flexibility of less than 80° indicates decreased hamstring extensibility, considered as short hamstring syndrome (Vakhariya et al., 2016).

Previous researchers have employed muscle relaxants and physical therapies (e.g., transcutaneous electrical nerve stimulation, local heat application, muscle energy techniques) to address short hamstring syndrome. Recently, studies have also investigated suboccipital muscle inhibition techniques, nerve mobilization techniques, static stretching, and proprioceptive neuromuscular facilitation (PNF) techniques (Jagtap & Mandale, 2015; Prajapati & Shukla, 2020; Caballero et al., 2014; Singh et al., 2017; Vakhariya et al., 2016). However, the high recurrence rates suggest that further research is needed to determine the most effective method for increasing hamstring flexibility (Valenza et al., 2015; Opar et al., 2012; Rodríguez et al., 2016).

Various studies have been conducted to increase hamstring flexibility. Bakhariya et al. (2016) applied suboccipital muscle inhibition techniques, nerve mobilization techniques, and static stretching to individuals with short hamstring syndrome, finding all three techniques to be highly effective, with static stretching being the most effective. De Ridder et al. (2020) reported that nerve mobilization might be more effective than regular static stretching in the long term for hamstring flexibility. Castellote-Caballero et al. (2014) suggested that nerve mobilization techniques could increase hamstring flexibility more than static stretching, whereas Singh et al. (2017) found that PNF stretching was more effective than nerve mobilization techniques. Pagare et al. (2014) compared nerve mobilization and static stretching, finding both techniques effective in increasing hamstring flexibility in soccer players with short hamstring syndrome. Thus, opinions among researchers differ, and it is unclear which intervention technique is more effective for increasing hamstring flexibility.

Recent studies have shown that distal interventions can increase hamstring flexibility, with suboccipital muscle inhibition techniques being effective (Prajapati & Shukla, 2020; Sojitra & Shukla, 2020; Panse et al., 2018). An interesting study by Haughey and Peter (2020) reported that changes in temporomandibular joint position due to wearing a mouthguard affected hamstring flexibility, suggesting that temporomandibular joint interventions could influence hamstring flexibility, highlighting the potential of distal interventions for hamstring flexibility.

Various theories have been proposed regarding the relationship between the temporomandibular joint and hamstrings, including the fascial connection theory, the descending inhibitory control pathway activation theory, the body flexion chain theory, and the posterior static chain theory, with the fascial connection theory being the most prominent (Fernández et al., 2006; Moon & Lee, 2011). While these theories lack scientific evidence, they provide a conceptual approach as theoretical backgrounds.

Blum (2008) reported a connection between pelvic pain and the temporomandibular joint, with the pelvis and temporomandibular joint related through fascial, muscular, referred pain, and spinal segment tension relationships. Chinappi and Getzoff (1994) found various connections between the jaw, head, spine, and pelvis, suggesting complex interactions involving 2,526 positions. Espejo-Antúnez et al. (2016) reported that PNF stretching techniques improved hamstring flexibility, temporomandibular joint dysfunction symptoms, mouth opening, and pain reduction in individuals with temporomandibular joint dysfunction. Another study showed that hamstring stretching improved hamstring flexibility, mouth opening, and pain in individuals with temporomandibular joint dysfunction and hamstring shortening. Yoon Samwon & Son Hohee (2017) reported that PNF interventions for the temporomandibular joint and hamstrings significantly improved forward bending, popliteal angle, and active mouth opening. Yurchenko et al. (2014) reviewed 41 sources, highlighting the deep connections between dentistry and other medical fields, suggesting that temporomandibular joint interventions could improve muscle pain, headaches, posture disorders, and other diseases. However, due to insufficient review of the various theoretical aspects of interdisciplinary relationships, the practical results remain unclear, necessitating further research in this field.

These studies indicate a potential relationship between the temporomandibular joint and hamstrings and suggest the possibility of increasing hamstring flexibility through temporomandibular joint interventions. However, the study by Haughey and Peter (2020) alone is insufficient to confirm the effects of temporomandibular joint interventions on hamstring flexibility. Additionally, the high recurrence rate and differing opinions on intervention effectiveness among researchers indicate a need for further research to determine the most effective method for increasing hamstring flexibility.

Therefore, this study aims to compare the effects of temporomandibular joint stretching techniques and suboccipital muscle inhibition techniques on hamstring flexibility over 8 weeks in adult men with short hamstring syndrome.

3.2. Purpose

The purpose of this study is to compare the effects of temporomandibular joint stretching techniques and suboccipital muscle inhibition techniques on hamstring flexibility over 8 weeks in adult men with short hamstring syndrome.

3.3. Definition of Terms

A. Short Hamstring Syndrome

(1) Theoretical Definition

Short hamstring syndrome refers to a condition where the hamstrings are shortened for unknown reasons. This can be identified using the straight leg raise (SLR) test and the finger floor distance (FFD) test. If the SLR test result is less than 80° or if the fingertips do not touch the floor in the FFD test, hamstring flexibility is considered reduced, indicating short hamstring syndrome (Vakhariya et al., 2016).

B. Temporomandibular Joint (TMJ)

(1) Theoretical Definition

The temporomandibular joint (TMJ) is a synovial joint consisting of the condylar head of the mandible and the mandibular fossa of the temporal bone. A disc located in the middle of the joint's fibrocartilage divides the joint cavity into an upper and lower compartment. The surrounding connective tissue, the joint capsule, attaches to the tendons along with the muscles. The joint capsule is surrounded by a synovium that secretes synovial fluid, and the articular disc attaches to the joint capsule, positioned between the condylar head of the mandible and the mandibular fossa of the temporal bone (Stocum & Roberts, 2018).

C. Stretching

(1) Theoretical Definition

The dictionary definition of stretching is a method of extending or lengthening muscles or tendons to maintain the muscles of the body (Jang & Jung, 2002). Stretching is known as a physical activity that continuously elongates specific muscles or muscle groups or tendons to feel or improve comfortable tension and gentle elasticity in those muscle groups. However, recent researchers have defined stretching as an action that involves the application of internal and external forces accompanied by movement, resulting in increased flexibility of soft tissues and range of motion in the joints (Weerapong et al., 2004).

(2) Operational Definition

In this study, the concept of stretching includes a temporomandibular joint stretching technique, which is a protocol verified by Stelzenmueller et al. (2016) and supplemented by the research team based on the TMJ correction technique by

Liem (2005).

D. Suboccipital Muscles

(1) Theoretical Definition

The suboccipital muscles consist of the rectus capitis posterior minor, rectus capitis posterior major, obliquus capitis superior, and obliquus capitis inferior. These muscles are related not only to rotational movements of the head but also to posture control. They have the highest density of muscle spindles in the body, serving as proprioceptive sensors that significantly contribute to head posture control and providing stability to the head and spine (Cho et al., 2015).

E. Flexibility

(1) Theoretical Definition

Flexibility is a physical characteristic defined as the ability to voluntarily move a joint through its full range of motion (Gonçalves et al., 2011). This characteristic depends on individual anatomical and physiological components, such as the muscle-tendon unit, ligaments forming the joint, the condition of bones and cartilage, and the stiffness reflex provided by neural spinal circuits (Kato et al., 2011).

3.4. Hypothesis

The hypotheses of this study are as follows:

- The group receiving temporomandibular joint stretching techniques will show significant changes in hamstring flexibility.
- The group receiving suboccipital muscle inhibition techniques will show significant changes in hamstring flexibility.

- The group receiving combined interventions of temporomandibular joint stretching techniques and suboccipital muscle inhibition techniques will show significant changes in hamstring flexibility.

3.5. Theoretical Background

A. Hamstring

The hamstrings are composed of four muscles: the semitendinosus, semimembranosus, and the long and short heads of the biceps femoris.

Semitendinosus

The semitendinosus is characterized by its long, cord-like tendon, which is divided by a tendinous inscription, distinguishing two separate muscle bellies. The tendon of the semitendinosus combines with the long head of the biceps femoris tendon to originate from the lower medial aspect of the ischial tuberosity and is located anterior to the semimembranosus tendon (Beltran, 2012). It runs over the medial collateral ligament of the knee and wraps around the medial condyle of the tibia, attaching to the pes anserinus complex behind the tendon of the sartorius, together with the gracilis, on the upper medial surface of the tibial body (Markee et al., 1955). The muscle-tendon complex and proximal tendon of the semitendinosus are the shortest among the hamstring muscles, constituting about 25-30% of the muscle length (Storey, 2012). The nerve supply to the semitendinosus comes from two main branches of the tibial nerve, which control the upper and lower portions of the muscle (Woodley & Mercer, 2005; Kellis et al., 2010).

Semimembranosus

The semimembranosus originates from the upper and outer deep part of the ischial tuberosity and is connected with the tendon of the adductor magnus and the origin of the long head of the biceps femoris (Koulouris & Connell, 2005). It is situated obliquely compared to the semitendinosus and the long head of the biceps femoris, and its tendon becomes broader and flatter as it extends, characterized by a thin, flat medial edge and a thicker, rounded lateral border. The semimembranosus has the longest proximal tendon among the hamstring muscles, comprising 72% of the muscle length and 53% of the distal portion, with the largest cross-sectional area (15.75 cm^2) in the hamstring complex (Woodley & Mercer, 2005). It primarily inserts on the horizontal groove of the medial condyle of the tibia. The nerve supply is from the tibial portion of the sciatic nerve, with some branches also supplying the distal portion of the semitendinosus.

Long Head of the Biceps Femoris

The long head of the biceps femoris originates from the medial aspect of the ischial tuberosity through a thick, rounded tendon, partially connected to the superficial fibers of the sacrotuberous ligament. The proximal tendon is relatively long (average 24 cm), extending up to 60.6% of the muscle length. The first muscle bundle forms a muscle-tendon complex in the proximal region, occupying 46.8% of the total muscle length (Garrett Jr et al., 1989). The biceps femoris complex has the second-largest cross-sectional area (10 cm^2) among the hamstrings and the longest distal tendon (average 27.5 cm), extending 62.6%, with the muscle-tendon complex constituting 66% of the muscle length. The proximal tendons of the long head of the biceps femoris and the semitendinosus form a combined tendon, with insertion points at the tibial plateau and the lateral aspect of the fibula (Chleboun et al., 2001). The long head of the biceps femoris is innervated by the tibial portion of the sciatic nerve, which typically splits into two primary nerve branches before entering the muscle (Seidel et al., 1996).

Short Head of the Biceps Femoris

The short head of the biceps femoris originates directly from the lateral intermuscular septum, the upper two-thirds of the lateral supracondylar line, and the lateral lip of the linea aspera. Its insertion is visually indistinguishable from the long head's distal tendon, attaching to the head of the fibula with two ligamentous insertions. It inserts directly on the tibial head and blends partially with the lateral collateral ligament, attaching approximately 1 cm below and lateral to the pes anserinus on the tibial tuberosity (Kusma et al., 2007). The muscle length, excluding the tendon, averages 25.8 cm, and 29.1 cm including the tendon, with the smallest cross-sectional area among the hamstrings. The nerve supply to the short head of the biceps femoris differs from the rest of the hamstring complex, typically provided by a single nerve branch from the common peroneal nerve, but previous studies have shown it may receive innervation from at least two nerve branches, with 2-3 branches running from the lateral aspect of the sciatic or common peroneal nerve (Woodley & Mercer, 2005; Sunderland & Hughes, 1946). Thus, the hamstrings anatomically consist of four muscles (semitendinosus, semimembranosus, long and short heads of the biceps femoris). The short head of the biceps femoris acts solely as a monoarticular knee flexor, while the other three muscles function as biarticular muscles involved in both hip extension and knee flexion. The hamstrings originate from the ischial tuberosity, sharing this attachment site with the gluteus maximus, piriformis, and lumbar multifidus, potentially influencing and being influenced by lumbar-pelvic muscles (Vleeming et al., 1996).

B. Fascial Connection Theory

Fascia is connective tissue found throughout the body, anchoring all organs and enveloping tissues and organs, including nerves, blood vessels, muscles, and bones, down to the cellular level (Butler, 1996; Comeaux, 2008). Since the central nervous system is surrounded by fascia, dysfunction in fascia can have widespread neurological impacts. Most fascial tissue is arranged vertically from head to toe, with four interconnected transverse fascial planes crisscrossing the body like a web. Therefore, injury in one part of the body can cause pain and dysfunction throughout the entire body due to this interconnected system. When fascia loses its function due to injury, disease, surgery, poor posture, or inflammation, it becomes tight and constricted, exerting abnormal pressure on nerves, muscles, bones, and organs. This excessive pressure can lead to pain, headaches, temporomandibular joint disorders, and restricted movement (Barnes, 1990;

DeLaune, 2008; Moon & Lee, 2011).

C. Activation of Descending Inhibitory Control Pathways

Stretching the hamstrings can activate descending inhibitory control pathways, reducing pressure pain sensitivity in hyperalgesic areas of other muscles. Stretching the hamstrings can activate the periaqueductal gray (PAG) in the midbrain, which in turn can activate descending inhibitory control pathways (Vicenzino, 1995). The descending fibers from the PAG to the medulla have lateral branches that end in various regions, including the upper cervical spinal cord (Carrive, 1995). The convergence of nociceptive afferents from the receptive fields of cervical C1-C3 and the masseter muscle in the trigeminal nerve occurs in the caudate nucleus (Bogduk, 1992). If hamstring stretching can activate the PAG, the reduced sensitivity will impact a larger number of muscles, including the masticatory muscles (Fernandez, 2006). Vicenzino et al. (1996) observed a trend of reduced pain immediately after cervical mobilization in subjects with lateral epicondylalgia, demonstrating that interventions at the cervical spine can have analgesic effects on distal areas like the lateral epicondyle.

D. Dynamic Synergist-Agonist: Flexor Chain of the Body

The masticatory muscles and the hamstrings are part of the body's flexor chain, which includes the cervical flexor chain, the trunk flexor chain, and the lower limb flexor chain. The cervical flexor chain consists of the temporalis, infrahyoid muscles, masseter (masticatory muscles), stylohyoid, genioglossus, geniohyoid, sternocleidomastoid, sternohyoid, thyrohyoid, sternothyroid, and platysma. The lower limb flexor chain includes the iliopsoas, obturator, semimembranosus, semitendinosus, popliteus, gastrocnemius, extensor digitorum longus, lumbricals, quadratus plantae, flexor hallucis brevis, and extensor digiti minimi.

Analyzing the components of the flexor chain reveals a dynamic synergist-agonist function between the masticatory muscles and the hamstrings. Both muscle groups reduce the angle between the bones to which they attach. The masticatory muscles close the mouth by reducing the angle between the maxilla and mandible, while the hamstrings flex the knee, reducing the angle between the femur and tibia. This functional relationship confirms the same function between both muscle groups, allowing dynamic agonist functions within each group (Fernandez, 2006).

The concept of dynamic synergist-agonist function was previously described by the authors of proprioceptive neuromuscular facilitation techniques (PNF) (Voss et al., 1989). This method suggests that the strong muscles of a muscle chain can help strengthen the weaker muscles of the same chain. Thus, we can infer that relaxation of one part of the muscle chain accompanies relaxation of the rest of the chain. The isometric contraction of the hamstrings can result in indirect contraction of the masticatory muscles (Fernandez, 2006). This small contraction can be sufficient to induce an isometric relaxation effect, leading to muscle relaxation (Lewit, 1999).

E. Static Synergist-Agonist: Posterior Static Chain of the Trunk

The Global Posture Re-education (GPR) method described by Phillipe Souchard (1994) includes various static chains, including the posterior static chain of the trunk. The posterior static chain consists of the posterior spinal muscles (posterior longitudinal ligament, iliocostalis, latissimus dorsi), pelvic muscles (piriformis, obturator, gemellus, hamstrings, gastrocnemius).

The function of these muscles is primarily to maintain an upright posture against gravity. A synergist-agonist relationship and gravity relationship can be established between the masticatory muscles and the posterior static chain of the trunk, with the temporalis playing a role in the gravity balance of the jaw (Cainarca & Sgobbi, 1998). According to this gravity relationship, we can assume that stretching the gravitational muscle tissue of the body can induce relaxation in the gravitational muscle tissue of the TMJ (Fernandez, 2006).

F. Suboccipital Muscle Inhibition Technique (SMI)

The suboccipital muscle inhibition technique is a method to relax the tension of four muscles located between the occiput and the atlas, which control the upper cervical vertebrae. The suboccipital muscles include the rectus capitis posterior minor, rectus capitis posterior major, obliquus capitis superior, and obliquus capitis inferior. These muscles are known to be involved not only in head rotation but also in posture control. The suboccipital muscles influence posture control and affect the results of related tests such as the straight leg raise test.

Moreover, relaxing the fascia of the suboccipital muscles, due to their high density of neuromuscular bundles, allows greater stretching and reduces the tension of knee flexors. This is because the hamstrings and suboccipital muscles are connected by a single nervous system passing through the dura mater. Myers (2004) called this the superficial back line (Bretischwerdt et al., 2010; Cho et al., 2015; Jagtap & Mandale, 2015).

G. Neurodynamic Sliding Technique

The neurodynamic sliding technique alternates movements involving at least two joints, where one movement increases neural tension by elongating the neural tract while the other movement simultaneously reduces neural tension by shortening the neural tract. This technique aims to mobilize the nerves with minimal increase in tension and has been reported to produce greater longitudinal movement of the nerves compared to techniques that simply elongate the neural tract, such as tensioning techniques (Coppieters & Butler, 2008).

H. Proprioceptive Neuromuscular Facilitation Technique (PNF)

The proprioceptive neuromuscular facilitation technique (PNF) is an advanced form of flexibility training that involves both the stretching and contracting of the targeted muscle groups. PNF stretching was originally developed as a form of rehabilitation. Although there are various forms of PNF stretching, they all have one thing in common: they all promote muscle inhibition. Various PNF techniques based on Kabat's concept include Hold-Relax, Contract-Relax, and Contract Relax Antagonist Contract (Kabat & Levine, 1953). The most representative technique is the Hold-Relax (HR) technique, which involves an isometric contraction of the shortened muscle against maximal resistance followed by a relaxation phase (Tanigawa, 1972).

I. Static Stretching Technique

The static stretching technique is a type of exercise performed in a static position without additional movements besides the stretching action of the muscles. Static stretching involves holding a stretch position for a specific period. The benefits of static stretching include preventing the tissue from absorbing a large amount of energy per unit of time, not causing a strong reflex contraction due to the slow stretching, and alleviating muscle pain. According to Smith (1994), static stretching is the safest, most frequently used, and least likely to cause injury.

4. Materials and Methods

4.1. Design

This study is a single-blind, randomized controlled trial (RCT) aimed at assessing the effects on hamstring flexibility in adult men aged 20-40 with short hamstring syndrome. Participants were allocated into three groups using stratified randomization (Suresh, 2011).

4.2. Subjects

The subjects of this study were selected with the cooperation of Phillip Co., Ltd. (Sports Club Phillip) in Bundang-gu, Seongnam-si, Gyeonggi-do. Research notices were posted on the company’s bulletin board to recruit participants who met the selection criteria, did not violate the exclusion criteria, and provided written consent for the study. A total of 48 participants were selected.

A. Selection Criteria

(1) Male subjects in their 20s and 30s

(2) Those with a straight leg raise (SLR) angle of 80° or less

(3) Those able to perform the forward flexion distance (FFD) test (Aparicio et al., 2009; Vakhariya, 2016)

B. Exclusion Criteria

(1) History of lower limb injury

(2) History of herniated disc or lumbar protrusion

(3) History of acute lower back pain

(4) History of lower limb pain or sensory abnormalities

(5) History of muscle-tendon injury in the hamstrings within at least one month before the study

(6) Subjects with knee or hip prostheses

(7) Subjects unable to assume test positions or physically unable to undergo interventions or evaluations

(8) Subjects using medications that could affect measurements (e.g., muscle relaxants) (Aparicio et al., 2009; Vakhariya, 2016)

C. Number of Subjects and Basis for Calculation

The appropriate sample size was calculated using G-power 3.1.9.7, applying mixed ANOVA, two-tailed test, medium effect size of 0.25 (Cohen, 2013), significance level of 0.05, and power of 0.8. The required sample size was determined to be 42, and considering a dropout rate of 10%, a total of 47 subjects were calculated. However, to maintain balance among the three groups, 48 subjects (16 per group) were selected.

D. Ethical Considerations

This study was conducted after obtaining approval from the Institutional Review Board (IRB) of CHA University to protect the rights of the subjects (Approval No.: 1044308-202201-HR-004-01). The study was also registered with the Clinical Research Information Service (CRIS, Clinical Research Information) (Unique ID, 1044308-202201-HR-004-01; CRIS Registration No., KCT0007083).

The researcher met with each subject to explain the purpose and intent of the study, obtained written consent for voluntary participation, and ensured anonymity and the right to withdraw from the study at any time. Subjects were informed that the survey data would be used only for research purposes and that all measurement documents would be shredded and destroyed in case of withdrawal or upon completion of the study.

4.3. Methods

A. Group 1: Temporomandibular Joint Stretching Technique (TMJ)

The temporomandibular joint stretching technique is based on the palpation method verified by Stelzenmueller et al. (2016) and the temporomandibular joint correction technique by Liem (2005), which have been modified and supplemented. This technique is performed for 8 weeks, with each session consisting of approximately 10 seconds per stretch, repeated 3 times per session, twice a week.

Position the subject comfortably lying on their back, looking up at the ceiling.
The subject opens their mouth approximately 3 cm for evaluation.

Using the examiner's middle finger, palpate along the upper gum line within the oral cavity, moving towards the location where the temporomandibular joint disc and mandibular condyle are closest to each other. During palpation, the examiner positions their fingertip between the maxilla and mandible and holds it fixed while the subject repeats the motion of opening and closing their mouth for approximately 10 seconds, three times [Figure 1].

Figure 1. temporomendibular Joint Stretching Technique

B. Group 2: Suboccipital Muscle Inhibition Technique (SMI)

Position the subject comfortably lying on their back, looking up at the ceiling.

The examiner sits at the head of the bed, placing their palms and fingers on the subject's occipital bone.

Using the examiner's third and fourth fingers, locate the space between the occipital bone and the atlas (C1).

With the metacarpophalangeal joints flexed at 90°, the examiner supports the base of the skull with their hands, applying gentle, consistent pressure using the second, third, and fourth fingers of both hands at a 90° angle, pulling lightly towards the head to relax the suboccipital muscles without causing pain.

Slowly release the pressure and gently lower the head back onto the bed. During the suboccipital muscle inhibition technique, the subject is instructed to close their eyes to avoid eye movement, which can affect suboccipital muscle tension [Figure 2].
This technique is performed once for approximately 2 minutes (Alberto et al., 2012; Aparicio et al., 2009).

Figure 2. suboccipital Muscle Inhibition Technique

C. Group 3: Combined Application of Temporomandibular Joint Stretching Technique (TMJ) and Suboccipital Muscle Inhibition Technique (SMI)

Group 3 applies both the temporomandibular joint stretching technique and the suboccipital muscle inhibition technique as mentioned in Groups 1 and 2.

For the temporomandibular joint stretching technique, the same method as Group 1 is applied, with approximately 10 seconds per stretch, repeated 3 times.
For the suboccipital muscle inhibition technique, the same method as Group 2 is applied, with approximately 2 minutes per session, performed once.

4.4. Tools

A. Straight Leg Raise Test (SLR)

To measure the straight leg raise test, a medical goniometer (29-5900; Goniometers bending Iron, P.K, Pakistan) used by Aparicio et al. (2009) was utilized. The subject lies in a supine position, and precise markers are placed on the head of the fibula, the lateral malleolus, and the lateral epicondyle of the femur using stickers. The axis of the goniometer is positioned at the prominence of the greater trochanter of the femur. The lower arm of the goniometer is placed parallel to the table and verified with a level (Type 70: aluminum level (300 mm), STABILA, Germany).

The subject maintains knee and ankle extension at all times, holds the talus, and avoids hip rotation. The hip flexion is gradually increased until the subject reports pulling or pain in the hamstring area or starts to bend the knee or move the pelvis. At this point, the upper arm of the goniometer is aligned along the line between the head of the fibula and the lateral malleolus, and the degree of leg elevation is recorded. According to previous researchers, this method has a high inter-rater reliability of 0.94-0.96 [Figure 3].

(Aparicio et al., 2009; Hui & Yuen, 2000; Medina & González, 1992)

Figure 3. straight leg raise test

B. Forward Flexion Distance Test (FFD)

For the forward flexion distance test, a manual measuring device (NFM-888; Nispo, Korea) was used. Subjects stand with knees fully extended, arms naturally extended, and bend their torso towards the floor while keeping their head and upper limbs relaxed. The subject bends forward until there is a tight discomfort in the hamstrings, then the vertical distance between the fingertips and the floor is measured using the manual measuring device [Figure 4]. According to Aparicio et al. (2009) and Cho & Ahn (2020), this method has a high inter-rater reliability with a correlation coefficient (r) of 0.96-0.98 (Pi & Chung, 2021).

Figure 4. forward flexion distance test

C. Popliteal Angle Test (PA)

To measure the popliteal angle test, a medical goniometer (29-5900; Goniometers bending Iron, P.K, Pakistan) as used by Aparicio et al. (2009) was utilized. The lower arm of the goniometer was verified for horizontal alignment using a level (Type 70: aluminum level (300 mm), STABILA, Germany). The subject lies in a supine position, and the hip and knee joints of the test leg are positioned at 90°. The axis of the goniometer is aligned with the lateral epicondyle of the femur. The subject is then instructed to extend the knee joint as much as possible, and the popliteal angle is measured three times to obtain an average value. During the test, care is taken to prevent any movement of the pelvis or hip joint [Figure 5]. (Aparicio et al., 2009; Yoon Sam-Won & Son Ho-Hee, 2017)

Figure 5. popliteal angle test

4.5. Data Collection

Data collection was conducted by posting a recruitment notice for research participants on the bulletin board of Sports Club Philip, located in Bundang-gu, Seongnam-si, Gyeonggi-do, from February 14 to February 18, 2022. A total of 48 participants who voluntarily expressed their intention to participate and met the selection criteria were recruited. Data collection occurred twice, before and after the intervention, over an 8-week period from February 21 to April 16, 2022. All data collection was carried out by a health exercise manager with over 10 years of experience, who measured the observation items.

Prior to the intervention, the researcher met with the participants to explain the purpose of the study and obtain consent forms. Before and after the intervention, a brief explanation of the test methods was given for about 10 minutes, followed by the tests. Data from 43 participants were used for statistical analysis, excluding 2 participants from the TMJ group, 2 participants from the SMI group, and 1 participant from the TMJ+SMI group.

4.6. Analysis Methods

To verify the collected data, SPSS 21.0 version (SPSS Inc, Chicago, IL, USA) was used for analysis with the following statistical methods:

The general characteristics of the participants across the groups were tested for homogeneity using one-way ANOVA.

Mixed ANOVA was used to compare and analyze the interaction between groups over time for each measured variable.

Post-hoc analysis was performed using Tukey HSD.

Paired t-tests were used to identify significant pre- and post-intervention changes within each group for each variable.

The straight leg raise test, forward flexion distance test, and popliteal angle test were analyzed using mean and standard deviation.

The significance level was set at $\alpha = 0.05$.

5. Results

5.1. General Characteristics

Between February 14 and February 18, 2022, 53 participants were screened, and 48 met the eligibility criteria. After obtaining written consent, the participants were randomly assigned to three groups: TMJ group (n = 16), SMI group (n = 16), and

TMJ+SMI group (n = 16). Over the 8-week period, 43 participants completed the study, excluding 2 from the TMJ group, 2 from the SMI group, and 1 from the TMJ+SMI group. The final analysis included 43 participants after excluding 5 who did not attend due to COVID-19 infection and personal reasons (Figure 6).

The general characteristics of the 48 participants who were initially deemed suitable for the study are as follows. All 48 participants were male. The mean age was 30.5 years (±5.4) for the TMJ group, 29.5 years (±6.5) for the SMI group, and 30.7 years (±5.2) for the TMJ+SMI group, with no significant age difference among the groups ($p = 0.829$). In the straight leg raise test, the TMJ group scored 70.9° (±7.9), the SMI group scored 70.7° (±6.6), and the TMJ+SMI group scored 74.5° (±7.0), showing no significant difference among the groups ($p = 0.296$).

In the forward flexion distance test, the TMJ group scored –3.8 cm (±1.8), the SMI group scored –3.4 cm (±1.7), and the TMJ+SMI group scored –2.6 cm (±1.6), with no significant difference among the groups ($p = 0.152$). In the popliteal angle test, the TMJ group scored 68.3° (±11.9), the SMI group scored 67.8° (±11.0), and the TMJ+SMI group scored 65.4° (±9.0), also showing no significant difference among the groups ($p = 0.732$) (Table 1).

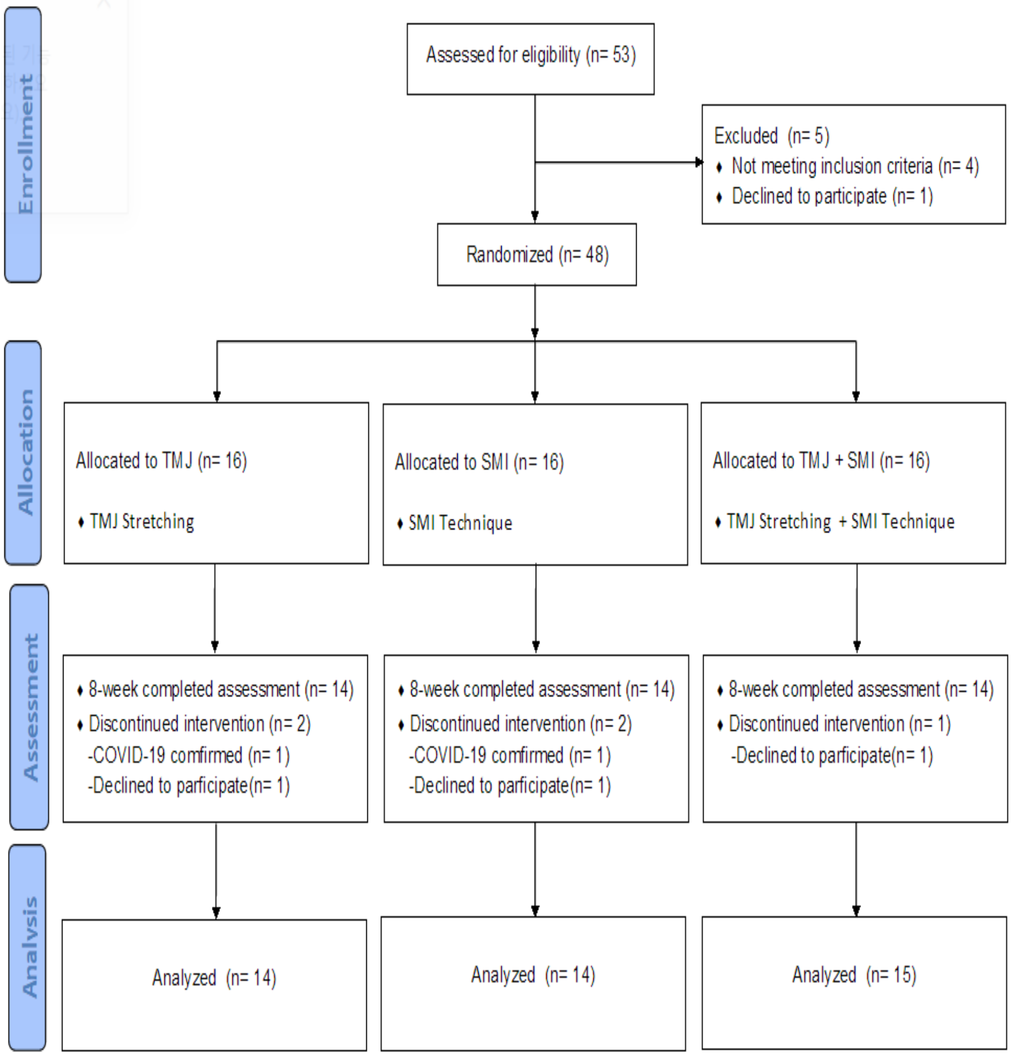

Figure 6. CONSORT flow diagram

Table 1. General characteristics of participants (n = 43)

variable	Categories	TMJ (n = 14)	SMI (n = 14)	TMJ + SMI (n = 15)	p
Age(year)		30.5 ± 5.4	29.5 ± 6.5	30.7 ± 5.2	0.829
Height(cm)		175.6 ± 7.8	176.6 ± 7.6	173.9 ± 7.6	0.635
Weight(kg)		76.8 ± 10.2	77.5 ± 12.8	73.7 ± 10.3	0.629
SLR Test(°)		70.9 ± 7.9	70.7 ± 6.6	74.5 ± 7.0	0.296
FFD Test(cm)		-3.8 ± 1.8	-3.4 ± 1.7	-2.6 ± 1.6	0.152
PA Test(°)		68.3 ± 11.9	67.8 ± 11.0	65.4 ± 9.0	0.732

2.

Values are expressed as mean ± SD. *$p < 0.05$

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique.

SLR, straight leg raise test; FFD, forward flexion distance test; PA, popliteal angle test.

5.2. Changes of Straight Leg Raise Test

The results of this study showed significant interaction effects among the TMJ group, SMI group, and TMJ+SMI group during the straight leg raise test ($p < 0.001$).

The TMJ group showed a significant increase in the pre- and post-intervention results within the group ($p = 0.03$).

The SMI group also showed a significant increase in the pre- and post-intervention results within the group ($p = 0.003$).

The TMJ+SMI group exhibited a significant increase in the pre- and post-intervention results within the group ($p < 0.001$).

The post-hoc test results indicated significant differences between the groups a and b ($p = 0.013$, $p = 0.011$).

Table 2. Changes of straight leg raise test (Degree)

	TMJ (n = 14)			SMI (n = 14)			TMJ + SMI (n = 15)			p
	Pre	Post	p	Pre	Post	p	Pre	Post	p	T × G
SLR	70.9 ± 7.9	72.5 ± 7.0	0.03	70.7 ± 6.6	72.4 ± 5.9	0.003	74.5 ± 6.8	84.1 ± 7.6	0.001	0.001* a: 0.013 b: 0.011

Values are expressed as mean ± SD. *p <0.05

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique.

SLR, straight leg raise test.

a: Significant changes in TMJ+SMI and TMJ groups.

b: Significant changes in TMJ+SMI and SMI groups.

T×G: Time and group interaction.

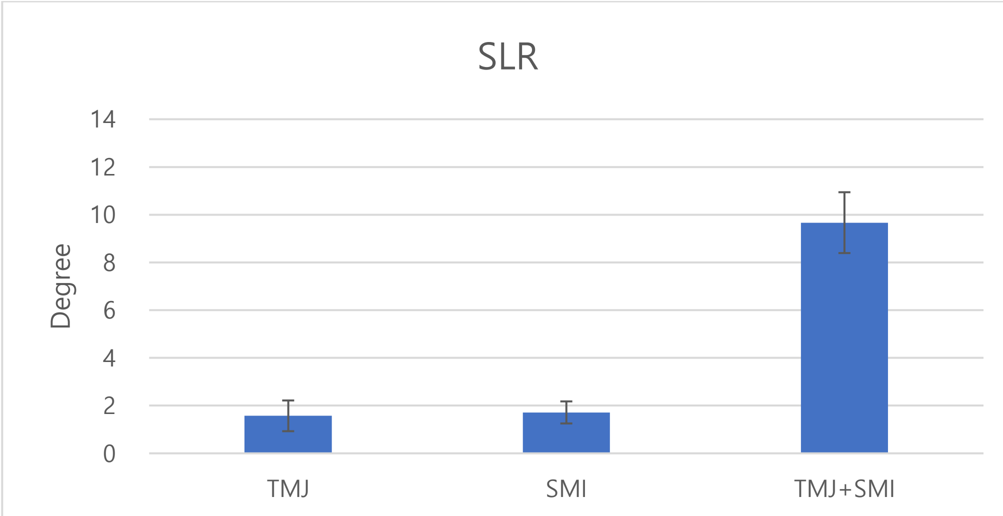

Figure 7. Results of straight leg raise test

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique. SLR, straight leg raise test.

5.3. Changes of Forward Flexion Distance Test

The results of this study showed significant interaction effects among the TMJ group, SMI group, and TMJ+SMI group during the forward flexion distance test ($p = 0.008$).

The TMJ group showed a significant increase in the pre- and post-intervention results within the group ($p = 0.017$).

The SMI group also showed a significant increase in the pre- and post-intervention results within the group ($p = 0.004$).

The TMJ+SMI group exhibited a significant increase in the pre- and post-intervention results within the group ($p < 0.001$).

The post-hoc test results indicated significant differences between groups a and b ($p = 0.011$, $p = 0.012$).

Table 3. Changes of forward flexion distance test (㎝)

	TMJ (n = 14)			SMI (n = 14)			TMJ + SMI (n = 15)			p
	Pre	Post	p	Pre	Post	p	Pre	Post	p	T × G
FFD	-3.8 ± 1.8	-1.8 ± 3.0	0.017	-3.4 ± 1.7	-2.1 ± 2.5	0.004	-2.6± 1.6	1.1 ± 1.6	0.001	0.008* a: 0.011 b: 0.012

Values are expressed as mean ± SD. *p <0.05

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique.

FFD, forward flexion distance test.

a: Significant changes in TMJ+SMI and TMJ groups.

b: Significant changes in TMJ+SMI and SMI groups.

T×G: Time and group interaction.

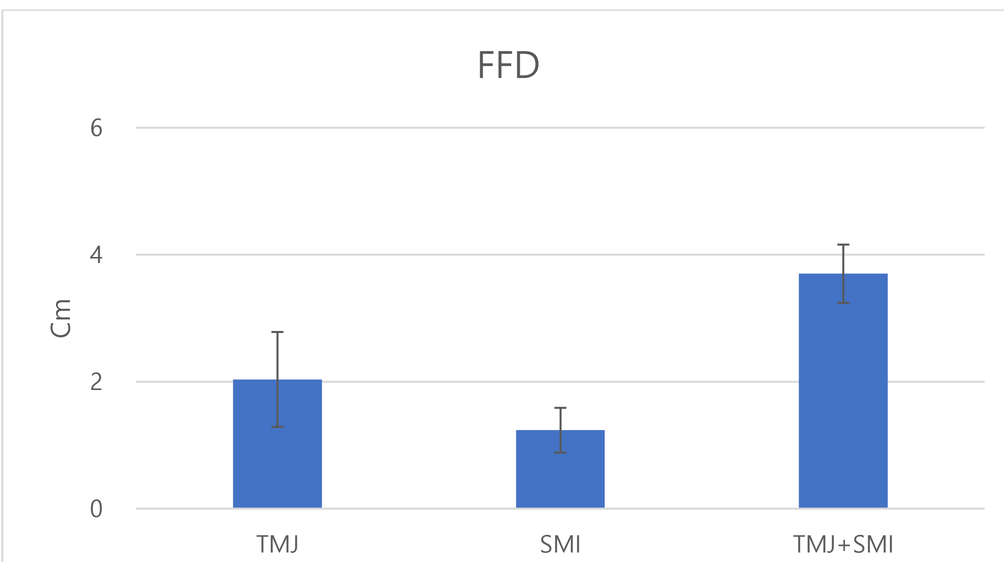

Figure 8. Results of forward flexion distance test

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique. FFD, forward flexion distance test.

5.4. Changes of Popliteal Angle Test

The results of this study showed significant interaction effects among the TMJ group, SMI group, and TMJ+SMI group during the popliteal angle test ($p < 0.001$).

The TMJ group showed a significant increase in the pre- and post-intervention results within the group ($p = 0.014$).
The SMI group also showed a significant increase in the pre- and post-intervention results within the group ($p = 0.004$).
The TMJ+SMI group exhibited a significant increase in the pre- and post-intervention results within the group ($p < 0.001$).

Table 4. Changes of popliteal angle test (Degree)

	TMJ (n = 14)			SMI (n = 14)			TMJ + SMI (n = 15)			p
	Pre	Post	p	Pre	Post	p	Pre	Post	p	T × G
PA	68.4 ± 11.9	70.3 ± 10.4	0.014	67.8 ± 11.0	72 ± 8.8	0.004	64.4 ± 9.0	74.4 ± 9.2	0.001	0.001*

Values are expressed as mean ± SD. *p <0.05
TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique.
PA, popliteal angle test.
T×G: Time and group interaction.

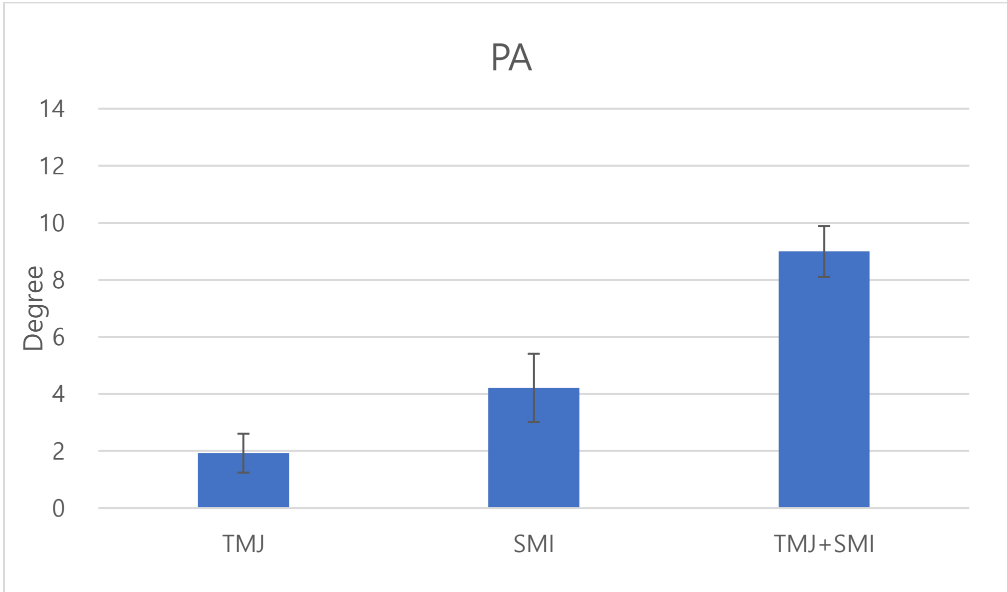

Figure 9. Results of popliteal angle test

TMJ, temporomandibular joint stretching technique; SMI, suboccipital muscle inhibition technique; TMJ+SMI, temporomandibular joint stretching technique and suboccipital muscle inhibition technique. PA, popliteal angle test.

6. Discussion

This study aimed to verify the effects of temporomandibular joint (TMJ) stretching techniques and suboccipital muscle inhibition techniques on the Straight Leg Raise (SLR) test, the Forward Flexion Distance (FFD) test, and the Popliteal Angle (PA) test. The results showed significant increases across all groups (TMJ, SMI, and TMJ+SMI) in these tests, both in group comparisons and within-group pre- and post-intervention analyses. Notably, the TMJ+SMI group demonstrated more significant increases compared to the TMJ and SMI groups. This indicates the clinical significance of the combined intervention of TMJ stretching techniques and suboccipital muscle inhibition techniques.

Previous studies have examined the effects of various interventions on the SLR test for subjects with hamstring shortening syndrome. Aparicio et al. (2009) reported a 5.9° increase after suboccipital muscle inhibition, Castellote-Caballero et al. (2014) reported a 9.86° increase after neural mobilization techniques, Mendez-Sanchez et al. (2010) reported a 3.7° increase after sustained hamstring stretching, and Hopper et al. (2005) reported a 4.7° increase after massage techniques to the hamstring muscles. In this study, the SLR test showed a 1.6° increase in the TMJ group, a 1.7° increase in the SMI group, and a 9.6° increase in the TMJ+SMI group. These results confirm the positive effects of interventions on the flexibility of subjects with hamstring shortening syndrome, consistent with previous studies. Particularly, the combined intervention of TMJ stretching techniques and suboccipital muscle inhibition techniques proved more effective in increasing flexibility.

Furthermore, previous studies have confirmed the increase in hamstring flexibility through the FFD test. Valenza et al. (2015) observed a 4.59 cm increase after diaphragmatic technique interventions, while Cho et al. (2015) and Kuan and

Haslan (2019) reported increases of 4.5 cm and 3.41 cm, respectively, after suboccipital muscle inhibition techniques. Vakhariya et al. (2016) observed a 9.9 cm increase after static stretching, and Itotani et al. (2021) reported a 5 cm increase after myofascial release techniques. In this study, the FFD test showed a 2 cm increase in the TMJ group, a 1.3 cm increase in the SMI group, and a 3.7 cm increase in the TMJ+SMI group. This suggests that TMJ stretching techniques combined with suboccipital muscle inhibition techniques have a more effective impact on flexibility.

The results of this study also confirmed significant interactions among the groups in the PA test, with increases of 1.9° in the TMJ group, 4.2° in the SMI group, and 10° in the TMJ+SMI group. These findings are in line with previous research, such as Ragia et al. (2021), who reported a 10.4° increase after PNF stretching techniques, Jagtap and Mandale (2015) who observed a 4.2° increase after suboccipital muscle inhibition techniques, O Deok-Won (2017) who noted a 4.4° increase after neural mobilization techniques, and Karthick et al. (2019) who reported a 13.76° increase after neural mobilization.

There have been no previous studies confirming the effects of TMJ stretching techniques on hamstring flexibility. This study's results confirmed that TMJ stretching techniques, combined with suboccipital muscle inhibition techniques, effectively increase flexibility, supporting Chinappi and Getzoff's (1994) findings that the TMJ, head, and spine are complexly interconnected. Yurchenko et al. (2014) also reported that the TMJ significantly impacts neuromuscular function, potentially improving conditions such as muscle pain, headaches, posture disorders, and other diseases. Similar to Espejo et al. (2016), who reported improvements in TMJ dysfunction after PNF stretching techniques for the hamstrings, and Yoon Sam-Won and Son So-Hee (2017), who noted improvements in hamstring flexibility and TMJ function after combined interventions, this study confirms the effectiveness of TMJ interventions on hamstring flexibility. Haughey and Peter (2020) also found that using a mouthguard to change TMJ positioning increased hamstring flexibility, further supporting the link between TMJ and hamstring flexibility.

This study's results indicate that combined TMJ stretching and suboccipital muscle inhibition techniques effectively increase flexibility in the SLR, FFD, and PA tests, consistent with previous research. However, direct scientific evidence for the impact of distal interventions on hamstring flexibility is still lacking, necessitating further research.

Thus, this study suggests that TMJ stretching techniques and suboccipital muscle inhibition techniques can serve as effective alternative methods for increasing hamstring flexibility in adult males with hamstring shortening syndrome.

The limitations of this study include:

- All subjects were male, so caution is needed when generalizing the results to females or the general population.
- This study only compared distal interventions; further research is needed on the effects of TMJ stretching techniques combined with proximal interventions.
- This study focused solely on hamstring flexibility, but future studies should also consider the associated pain in the intervention areas.

7. Conclusions and Recommendations

7.1. Conclusions

This study confirmed that temporomandibular joint (TMJ) stretching techniques and suboccipital muscle inhibition techniques are effective in increasing hamstring flexibility. Additionally, combined interventions of TMJ stretching and suboccipital muscle inhibition were found to be more effective than single interventions in increasing hamstring flexibility in adult males with hamstring shortening syndrome. Therefore, these techniques could be usefully applied to healthy adult males with hamstring shortening syndrome.

7.2. Implications of the Study

This study holds significance as preliminary research suggesting that TMJ stretching techniques and suboccipital muscle inhibition techniques can be referenced for a multifaceted integrative approach to increasing hamstring flexibility in adult males with hamstring shortening syndrome.

7.3. Recommendations

Based on the results of this study, the following recommendations are made:

a. Future research should compare the effects of combined distal interventions with combined proximal and distal interventions on subjects with hamstring shortening syndrome.

b. Studies should be conducted on the effects of TMJ stretching techniques on thoracolumbar flexion.

c. Direct, scientific, theoretical research should be conducted on the relationships between the TMJ, suboccipital muscles, and hamstrings.

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