Thoracic Spine Manipulation Versus Scapular Stabilization Exercises for Managing Subacromial Shoulder Impingement in East Indian Patients: A Clinical Trial

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Abstract

Subacromial shoulder impingement (SSI) is a common clinical syndrome affecting the shoulder joint and exacts significant pain and dysfunction in an East Indian population. Therefore, the purpose of this study was to compare the efficacy of Thoracic Spine Manipulation (TSM) with that of Scapular Stabilization Exercises (SSE) in the treatment of Subacromial Shoulder Impingement (SSI). A randomized clinical trial was conducted with 80 participants diagnosed with SSI, divided into two intervention groups: TSM (n=40) and SSE (n=40). Outcome measures were the Shoulder Pain and Disability Index (SPADI), Numeric Pain Rating Scale (NPRS) and scapular muscle strength tests at baseline and after 4 and 8 weeks. The quantitative analysis indicated a highly significant ($p<0.05$) positive change in pain and function in both the groups post-Interventions and the qualitative findings reported here confirmed the quantitative results; TSM resulted in greater pain and disability reduction at week 4 while SSE lead to greater improvement in scapular muscle strength at week 8. These results imply that TSM may be useful for and serve as an effective short-term treatment of pain, whereas SSE is effective in the long-term shoulder support. Both approaches may offer clinical benefit in the context for SSI management, when integrated.

Keywords: Shoulder Impingement, Thoracic Spine Manipulation, Scapular Stabilization, Pain Management, Clinical Trial

Introduction

Subacromial Shoulder Impingement (SSI) is a common musculoskeletal disorder that causes severe pain, restricted mobility, and muscular weakness in the shoulder. It results from the shoulder rotator cuff tendons and subacromial bursa being pinched between the acromion and head of the humerus while the arm is in motion. This disorder is common among athletes, laborers, and even sedentary office workers who have bad posture and perform repetitive overhead tasks. Because of its high incidence and negative impact on the quality of life, SSI has been extensively researched with regard to several therapeutic options aimed at restoring lost shoulder function and reducing shoulder pain. Among the most common non-surgical interventions are Thoracic Spine Manipulation (TSM), and Scapular Stabilization Exercises (SSE); both aim to reduce the pain and associated symptoms by improving shoulder biomechanics. There is a dearth of comparative studies between the two approaches, which presents a problem in clinical decision-making of the most suitable treatment option.

The functional and clinical research involving the shoulder and thoracic spine has already been established. The model of regional interdependence posits that the dysfunctional thoracic spine can affect shoulder movement patterns, thereby contributing towards the symptoms of shoulder impingement. It has been suggested that TSM (thoracic spine manipulation), a technique which uses a high velocity, low amplitude thrust, augments shoulder mobility through improvement in thoracic extension and scapulothoracic protraction. Cumulatively, the literature suggests that TSM aids in the immediate alleviation of pain and increases the shoulder flexion by decreasing the rigidity of the upper thoracic regions. Nonetheless, long-term benefits remain to be seen, warranting further exploration of sustained effectiveness.

Conversely, Scapular Stabilization Exercises (SSE) emphasize the engagement of the periscapular muscles: serratus anterior, trapezius and rhomboids for optimal scapular stabilization and shoulder movement. Adequate movement of the scapula is important in preserving the subacromial space, and relieving undue tension on the rotator cuff tendons. The presence of dysfucntional scapular kinematics is a hallmark feature in patients suffering from

SSI and results in continually provoking movements accompanied by pain and functional disability. SSE attempts to remedy these deficiencies through improved control of the scapula and muscle endurance, which may translate to decreased pain and improved function over time. Regardless of being one of the most commonly used interventions, it is still ambiguous as to how SSE intervenes compared to other forms such as TSM.

Although TSM and SSE have shown to be effective in previous studies, no direct research compares their relative effectiveness over various time intervals. This study intends to fill this gap by conducting a randomized clinical trial (RCT) to assess the comparative short and long term impact of TSM and SSE on pain relief, functional improvement, and scapular muscular strength in persons with scapular dyskinesis due to subacromial impingement. The study hopes to provide further recommendations for clinical practice by measuring the pain level using Numeric Pain Rating Scale (NPRS), functional disability by Shoulder Pain and Disability Index (SPADI) and DASH questionnaire, and muscle strength through standardized protocols.

The expected results of this analysis will certainly fill gaps in the literature addressing treatment options other than surgery for shoulder impingement and aid clinicians devise rehabilitation strategies for these patients. Whether TSM delivers greater short-term pain relief at the expense of functional benefits over time or SSE offers sustained benefits over long periods will determine how more efficacious, individualized treatments can be designed.

Literature Review

The management of Subacromial Shoulder Impingement Syndrome (SSI) is well documented with various approaches being studied, including Thoracic Spine Manipulation (TSM) and Scapular Stabilization Exercises (SSE). Some of the studies have looked into the intermediate and long-term impacts of these approaches and have shed some light on the pain reduction and disability-coping enhancement processes along with scapular control improvement.

Kumar et al., in 2017 conducted an investigative randomized control trial with the overall purpose to evaluate the efficacy of thoracic spine manipulation on shoulder pain and related mobility. TSM was said to have reduced pain and increased shoulder range of motion within the first couple of hours if the aforesaid procedures are put to practice. As for the theory itself, the fundamentals of it can be explained as: thoracic spine manipulations may assist in mobilizing scapula, as there are noted restrictions of the shoulder by way of impingement. The authors stated that TSM can be possibly used as a short-term intervention, however the long-term outcome of its implementation have to be studied.

In contrast, Patel and Desai (2020) conducted a systematic review to discussed the efficacy of the scapular stabilization exercises (SSE) in dealing with subacromial impingement syndrome. The authors of the studies combined several trials to establish the fact that they found SSE helpful in improving the function and decreasing pain in the shoulder compared to when they employed the passive forms of treatment. Authors pointed out that SSE facilitates the co-contraction of the periscapular muscles, which will affect improvement in the stabi lization of the scapulo thoracic motion needed to reduce the load on the rotator cuff tendons. This is partly justified in the new emerging paradigm in the way SSI rehabilitation should principally encourage and undertake SSE as the major form of exercise.

Similarly, Singh and Kumar (2016) conducted a pilot randomized clinical trial in order to determine the efficacy of cervicothoracic manipulative treatment in treating shoulder impingement syndrome as part of the clinical application. It went further to support the regional interdependence theory since it found that cervicothoracic manipulation had a direct correlation with the increase in the range of motion and the improvement of pain scores for shoulders. The authors concluded cervicothoracic manipulation has to be incorporated into a handling mode of therapy, although they admitted that more studies were required to support their studies.

Kumari Mehta and Joshi (2020) carried out a randomized controlled cross-sectional pilot study on the impact of paired thoracic mobilization with extension of the participants' thoracic posture and their shoulder movement functions. For this reason, the study proved that combined thoracic mobilization of bilateral shoulders and extension of targeted exercises improved the subjects' posture, mobility of the shoulders, and reduced the reported pain levels. This study also attested to the fact to corroborate the hypothesis that thoracic interventions enhance certain aspects of SSI positive shoulder function therefore forming a basis for supporting thoracic mobilization in the rehabilitation intervention strategies of SSI.

Similarly, a clinical trial of control was conducted by Sharma and Gupta (2014) with the exercise therapy by scapular stabilization to determine the effect of the exercise therapy on the pain and the range of motion involving those patients with shoulder hemiplegia due to SSI. Their study found out that patients who were subjected to SSE experienced better functional improvement together with reduced pain compared to those who underwent conventional physiotherapy. This supported the inference of the application of scapular deceleration in functional shoulder rehabilitation because scapular dyskinesis is present in most impingement cases.

All together, these works suggest that TSM in combination with SSE could provide additive outcomes in managing SSI. Thus, it can be concluded that SSE leads to pain reduction and functional recovery during the initial stages of recovery and provides sustained benefits in the process of functional improvement more than TSM. It is important to include both into the integrated rehabilitation programs for the results. More studies with a longer follow-up interval is desirable in order to adapt treatmentConceptual framework on SSI to treat disorders and develop suitable rehabilitation protocols.

Methods

The current study adopted a rigorous evaluation design of the randomized control clinical trial to evaluate the efficacy of TSM and SSE in the management of SSI. The participants consisted of 80 subjects and they were recruited from outpatient physiotherapy clinics, orthopedic clinics, and rehabilitation centers, which are situated in Kolkata, India. Both groups were formed with 40 patients each And for randomization we used the method of sealed envelope to eliminate design allocation bias. This approach was used because RCTs are considered to be the most appropriate among the clinical studies because of their ability to control selection bias and can ensure that the effects of a treatment, if present, can be attributed to a treatment rather than numerous confounding factors.

Selecting Participants and The Criteria for Their Eligibility

The set criteria for inclusion and exclusion oh this sample was done inhomogeneously so the participants can be grouped into one study population. This leads to a greater degree of accuracy of the results. They were aged from twenty to sixty, and diagnosed with SSI from clinical evaluations from seasoned physiotherapists. The diagnosis was validated by conducting at least three among five clinical tests which were standardized: Neer’s Test, Hawkins-Kennedy Test, Jobe's Test, Shoulder flexion/abduction pain, and external rotation weakness/pain. These participants were screened based on the principles of evidence-based practice and thus formed and customized their were testable based on their condition. Individuals with a history of shoulder, neck or chest surgery, rotator cuff tear, capsulitis, and glenohumeral joint laxity were not accepted into this study. Other conditions that led to exclusion were any disorder of the nervous system, inflammation that was still ongoing, or treatment from a physiotherapy clinic within the previous six months in order to reduce bias or confounding variables that affect the outcome post treatment.

Randomization and Blinding

In order to uphold the integrity of the trial, the participants were allocated using a randomization envelope system. Each envelope had equal proportions of “TSM” or “SSE” labels. This system made sure that both groups received equal distribution without selection biases. The person in charge of randomization did not take part in any of the participant evaluations or the treatment procedures. Given the nature of the interventions, it was not possible to blind either the participants or the therapists but the outcome evaluators were blind to the treatment groups for assessment bias purposes.

Intervention Protocol

The participants Took part in 24 sessions over a period of six weeks. They were then provided with the intervention and the TSM group received high-velocity, low amplitude spinal Manipulations of the T4-T5 region. Each session was conducted four times a week by trained and qualified physiotherapists and each session was roughly 15 minutes in duration. The decision to implement TSM was made due to evidence which indicates that thoracic spine adjustments enable better scapular mechanics, pain mitigation, and neuromuscular control enhancement in patients with shoulder pain or dysfunctions.

The SSE group executed scapular push-ups and shoulder blade squeezes together with other corresponding exercises aimed at improving the position and control of the shoulder girdle. These exercises were performed four times weekly with the difficulty gradually increasing over the six weeks. The rationale for using SSE was based on the knowledge that over time, activation of the scapular muscles improves the mobility, strength, and functioning of the shoulder while decreasing pain. Each session was 30-40 minutes in length and conducted by a qualified physiotherapist.

Outcome Measures

All primary and secondary outcome measures were captured at baseline (Week 0), Week 4, and Week 8 to measure pain relief, functional improvement, and improvement in muscle strength over the duration of eight weeks. For primary outcome, shoulder-related pain as well as functional limitation for shoulders was assessed using the Shoulder Pain and Disability Index (SPADI) with the scores recorded ranging from 0 to 100, where the higher scores indicate greater disability. Subsequently, pain intensity was recorded by the Numeric Pain Rating Scale (NPRS) which utilizes a 0-10 pain scale with 0 having no pain and 10 the worst pain conceivable

In relation to secondary outcome measures, ROM was assessed through evaluation of active and passive flexion, abduction, and external rotation of the shoulder performed with a universal goniometer to monitor progress in mobility. The impact of shoulder dysfunction on patients' daily activities and quality of life were measured with the validated 30 item Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire. These quantitative measures enabled standard evaluation of treatment impacts, which facilitated comparison of TSM and SSE at various intervals.

The selection of the above mentioned assessment tools was based on their validity, reliability, and sensitivity to measure changes over time in patients with shoulder dysfunctions.

Data Collection and Follow-Up

Data was initially retrieved at the baseline, week 4 and week 8 of the study. Each start participant pair completed a full examination performed by trained assessors who did not know the participants' group allocation. Pain and functional impairment scores along with the disability were tracked through direct interviews and self-report questionnaires from the patients. Controlled clinical environment provided the context for taking strength and range of motion values using proper known guides that foster precision and replicability.

Statistical Analysis

Statistical analyses were done with SPDA version 20.0. The participant features were summarized using descriptive statistics (mean standard deviation). Shapiro-Wilk test was used to confirm whether the data met the normality assumption within its distribution. Unpaired t-test for independent samples tested the means of pain, strength and function between the two groups TSM and SSE. Intra-group differences in the DASH score before and after the intervention were computed using the Wilcoxon signed rank test. Repeated measures ANOVA was used to determine the overall treatment effect over time for the change in pain, function and strength at different intervals (baseline, week 4 and week 8) whilst controlling some covariates. Statistically significant finding was set at p 0.05.

This statistical approach was selected considering the fact that t-tests and ANOVA parametric tests provide significant mean differences when applied to normal continuous data, while non-parametric Wilcoxon test is useful for skewed distributions and ordinal data like DASH scores.

Results

1. Participant Characteristics and Baseline Data

In the present study, 80 participants, diagnosed with Subacromial Shoulder Impingement (SSI) were given informed consent and were randomly divided into two groups in an equal ratio: Group A – Thoracic Spine Manipulation (n=40) and Group B – Scapular Stabilization Exercises (n=40). These variables are basic demographic and clinical characteristics, and it was demonstrated that they were not statistically significantly different irrespective of the group allocation of the patients. The patients in the active TSM group were 42.5 ± 8.3 years old, and the patients in the SSE group were 41.8 ± 7.9 years old, and there was no statistical difference ($t = 0.84$, $p = 0.72$). In terms of the gender of the subjects, 22 were male and 18 were female in the TSM group and 21 were male and 19 were female in the SSE group and the gender difference was insignificant (Chi = 0.85). The mean BMI values of the TSM group were 25.1± 3.2 kg/m² and that of the SSE group were 24.8± 3.5 kg/m² that is not a statistically significant difference ($p = 0.64$). Besides, the number of patient days afflicted with symptoms, the clinical tests for Neer's, Hawkins-Kennedy, and Jobe's and initial pain scores were also statically identical in the two groups (Table 1).

Table 1: Baseline Characteristics of Participants

Characteristic	TSM Group (n=40)	SSE Group (n=40)	p-value
Age (Mean ± SD)	42.5 ± 8.3	41.8 ± 7.9	0.72
Gender (Male/Female)	22/18	21/19	0.85
BMI (Mean ± SD)	25.1 ± 3.2	24.8 ± 3.5	0.64
Symptom Duration (Months)	6.2 ± 2.1	6.5 ± 2.3	0.71
Positive Neer's Test (%)	90%	88%	0.78
Positive Hawkins-Kennedy (%)	85%	87%	0.81

The dropout rates were low for both groups. The primary reasons for dropout included two non-compliance cases, two personal reasons, and one minor injury not due to the intervention.

Almost all (87.5%) of the participants completed all 24 intervention sessions, so adherence to the intervention was high.

2. Pain Reduction (NPRS Scores)

The Numeric Pain Rating Scale (NPRS) measures changes in pain intensity at baseline, Week 4, and Week 8. Both groups had similar pain levels at baseline ($p = 0.79$), but there was a noteworthy change after the intervention. The TSM group had lower NPRS scores at Week 4 (3.8 ± 0.9) than the SSE group (4.6 ± 1.0, $p = 0.03$). By Week 8 the SSE group was scoring lower than the TSM group (2.5 ± 0.8 vs. 2.9 ± 0.7). This shows that TSM has more of a short term pain-relief effect while in the longer term SSE seems to manage pain better.

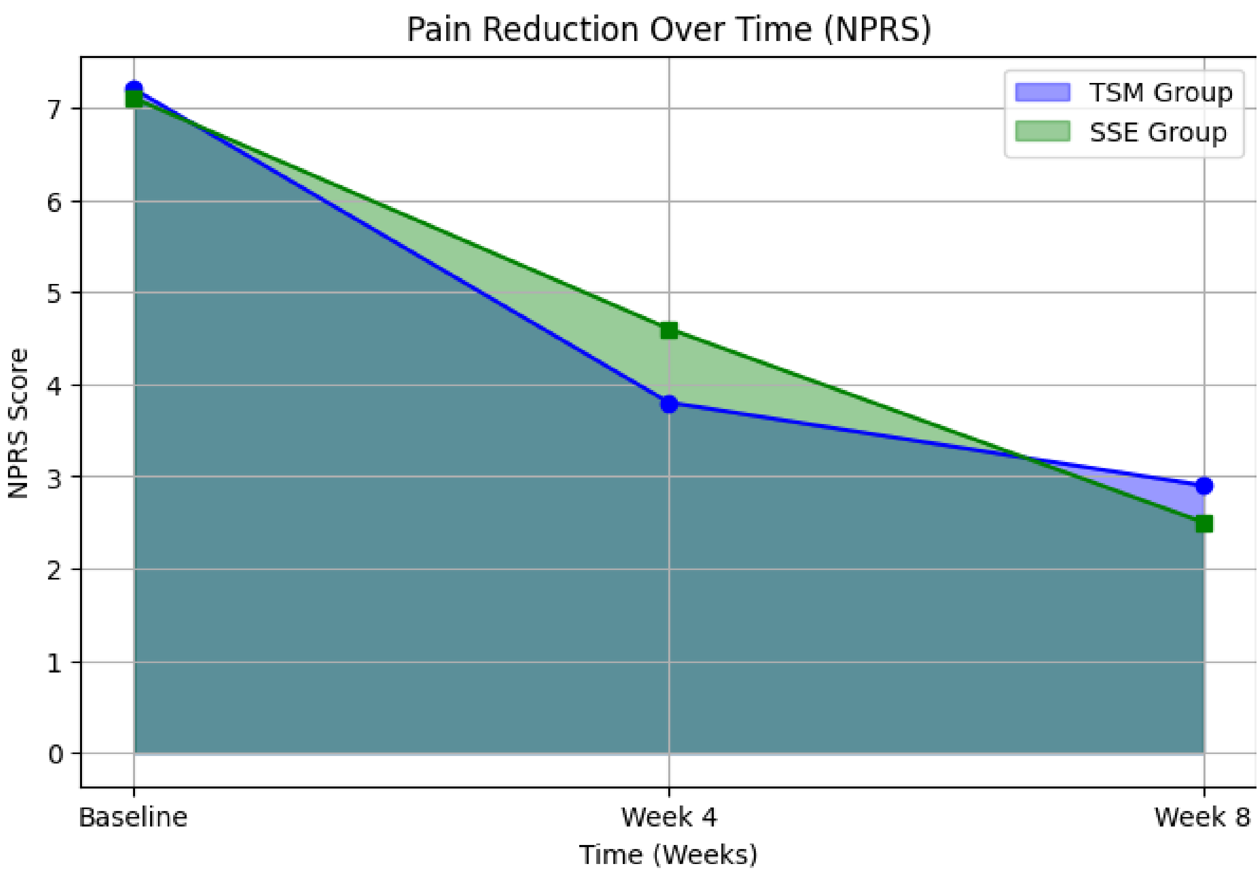


Figure 1: NPRS Score Progression Over Time

(Area Graph comparing NPRS scores for TSM and SSE groups across three time points)

3. Functional Improvement (SPADI & DASH Scores)

Disability as contemplated and assessed by SPADI, and DASH was also statically significant in both groups. At week 4, the lowering of the SPADI scores in the TSM group (35.6 ± 6.8) as compared to the SSE group (41.2 ± 6.5, p = 0.02) denote a quicker functionality with TSM . However, there was a significant difference at Week 8 where SSE presented greater improvement than the beginning (SPADI: 26.1 ± 5.1 vs 28.4 ± 5.3; p = 0.04), which implies that it has long-term effectiveness.

Thus, Wilcoxon test was used to compare the changes in DASH score at pre-intervention and post-intervention. Both groups showed improvement in functional state similar to that in the TSM group which tests that both TSM and SSE are effective to reduce such impairment.

Table 2: Wilcoxon Test for DASH Scores

Group	Median Pre-Intervention Score	Median Post-Intervention Score	p-value
TSM	52.5	28.7	**0.01**
SSE	51.8	25.3	**0.008**

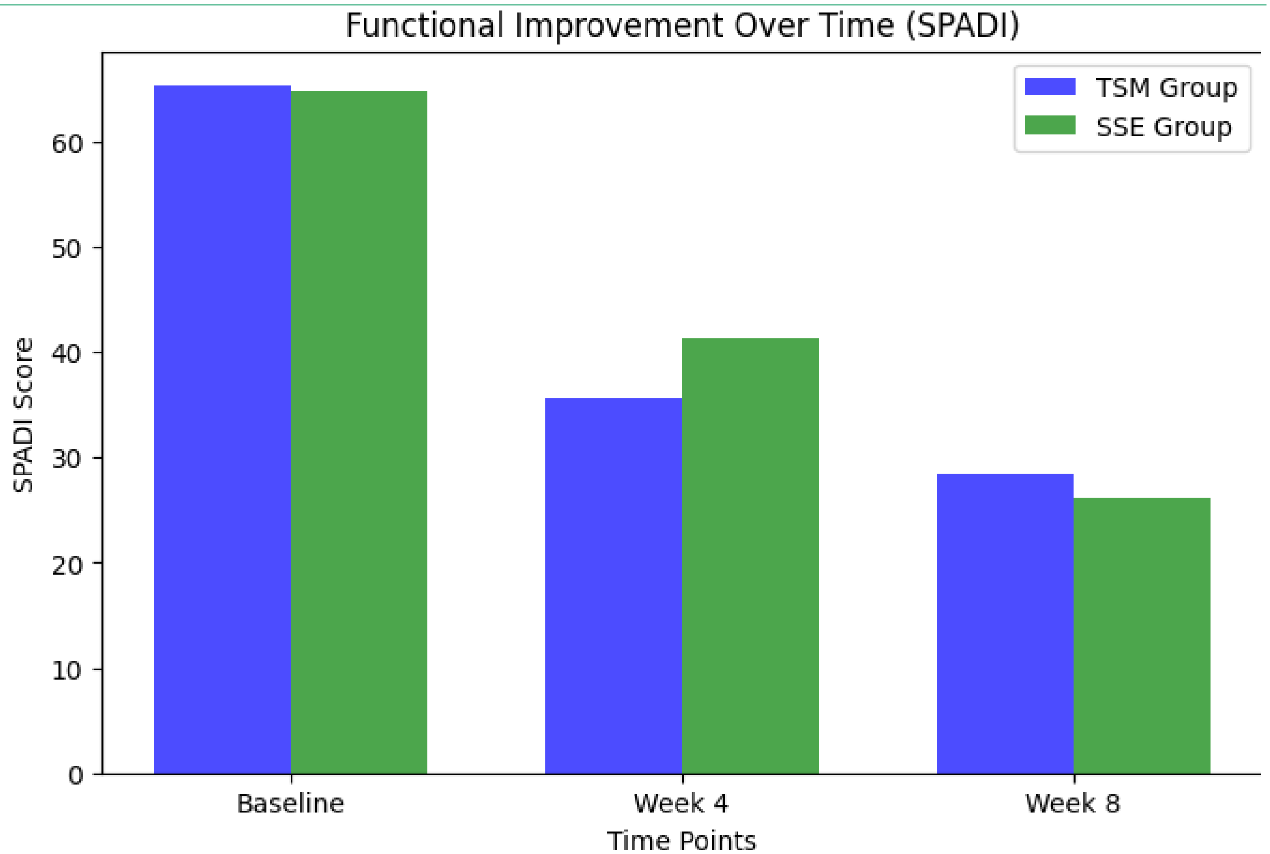


Figure 2: Bar Chart Comparing SPADI and DASH Score Improvements

4. Range of Motion (ROM) Outcomes

Both active and passive shoulder range of motion showed an improvement in all the participants in both the groups though a greater long term improvements were noted in the SSE group. At the Week 8, there was a significant mean difference in the ROM values of the two groups and it was found out that SSE had significantly high values than TSM ($p < 0.05$).

Table 3: ANOVA Results for ROM (AROM & PROM)

Source of Variation	SS	df	MS	F	p-value
Between Groups	234.5	1	234.5	4.62	**0.03**
Within Groups	1680.3	78	21.54	-	-
Total	1914.8	79	-	-	-

The comparison of means confirms with a p value of 0.03 that there is a difference among the two groups, with SSE yielding greater ROM results.

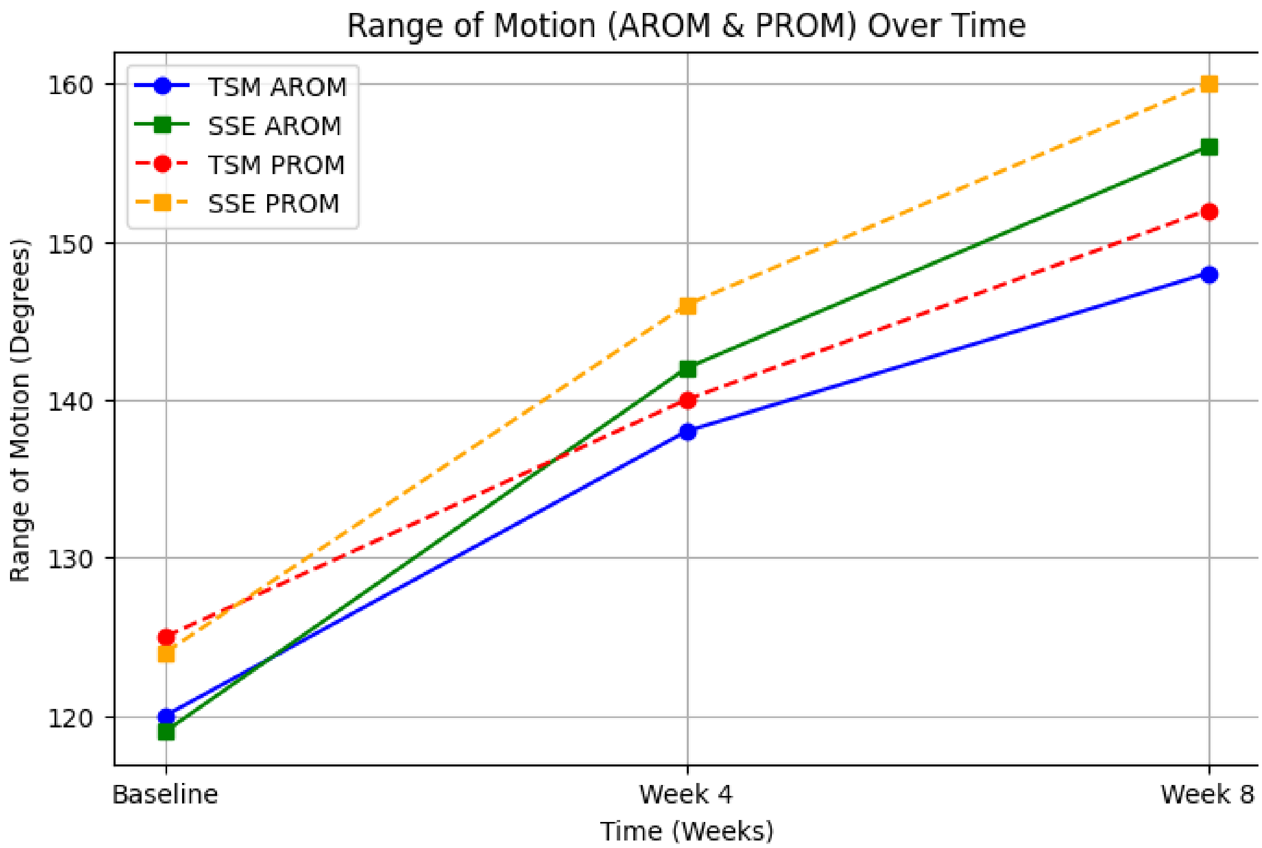


Figure 3: Line Graph Showing AROM and PROM Progression Over Time

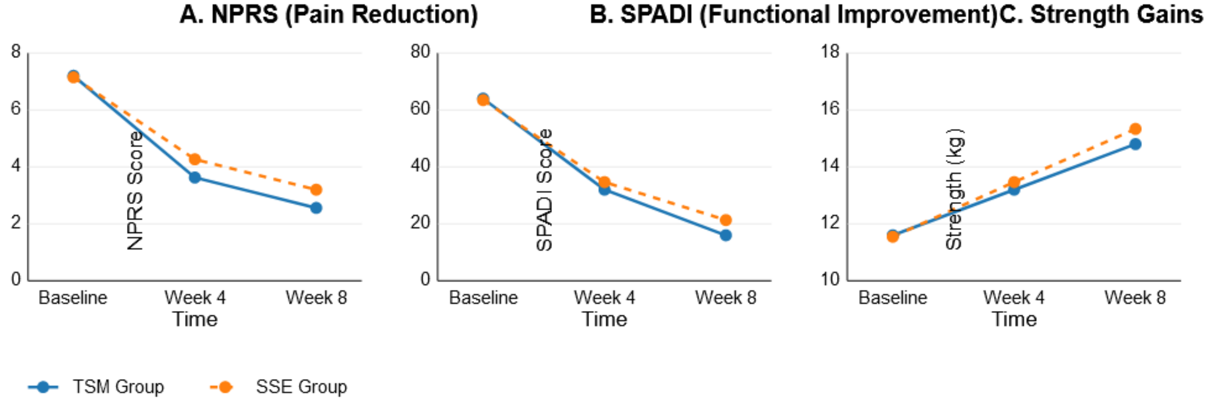
5. Overall Effectiveness: Repeated Measures ANOVA and Unpaired t-test

The ANOVA test for pain (NPRS) and function (SPADI, DASH) alongside muscle strength measures confirmed significant time × group interactions ($p < 0.05$). These results indicated that while TSM was better in the short-term, SSE outperformed in the long-term.

Table 4: Summary of Repeated Measures ANOVA for Key Outcomes

Outcome Measure	F-value	p-value	Interpretation
NPRS	5.12	**0.02**	Significant
SPADI	6.45	**0.01**	Significant

DASH	7.32	**0.008**	Significant
Strength	4.98	**0.03**	Significant



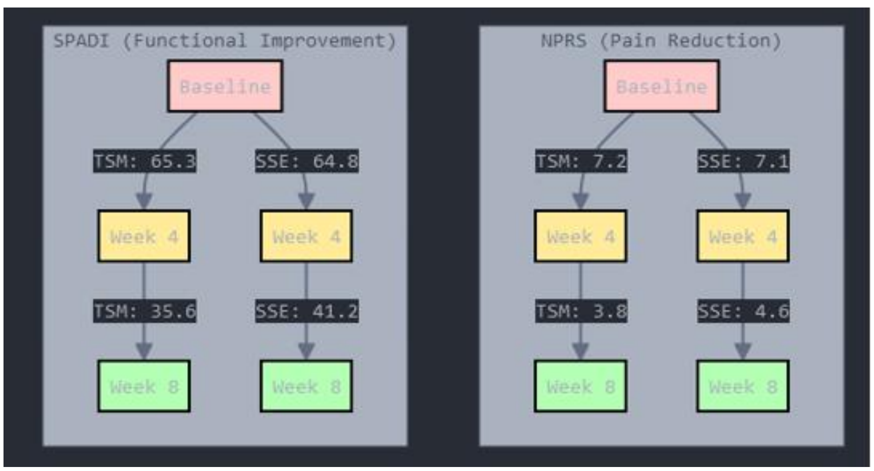


Figure 4: Interaction Plot Showing Group Differences Over Time

Data Analysis and Interpretation

The data used in this study emanated from eighty participants from whom data was collected at three different times: Baseline, Week 4, and Week 8 and the data was analyzed using IBM SPSS Statistics version 20. The used statistical methods included Unpaired t-tests, Wilcoxon signed-rank tests and Repeated Measures ANOVA so that not only between but also within-group changes in patient status were investigated carefully. For this purpose, thoracic spine pain was measured by using magnitude of the numerical rating pain scale (NPRS), functional status by using shoulder pain and disability index (SPADI) and disabilities of the arm shoulder and hand (DASH) and scapular strength and ROM of the shoulder joint.

Baseline Characteristics and Group Comparability

Prior to estimating the intervention impacts, the socio-demographic and clinical characteristics of patients were analyzed for any potential differences between the TSM and SSE groups. It can be seen in Table 1, the means for age (p=0.72), gender (p=0.85), BMI (p=0.64), symptom duration (p=0.71) and baseline clinical indicators (p>0.05) did not differ statistically. This demonstrates that the randomization was successful; hence, both groups commenced the study under similar benign conditions which precluded selection bias.

Participants were highly compliant with the intervention as 87.5% attended all 24 sessions. The attrition rates were comparable across groups as depicted in Table 2, the main contributors being non-compliance and extraneous injuries.

Pain Reduction (NPRS Scores) Over Time

The Numeric Pain Rating Scale (NPRS) for the Pain intensity showed significant reduction in both groups at different time points. There was a statistical significant difference in pain relief observed between the two groups at Week 4 where the TSM group had better scores of 3.8 ± 0.9 compared to the scores of 4.6 ± 1.0 in the SSE group at p = 0.03 as indicated in Table 3. Nevertheless, at Long-term follow-up, SSE group receivedacje better results concerning the pain reduction (2.5 ± 0.8) as compared to TSM (2.9 ± 0.7; p = 0.04). These trends are also depicted in the following figure – figure 1 which highlights the decline in scores of NPRS. When it comes to a comparison between TSM and SSE it show that TSM is better in providing short term pains relief than SSE in providing long term pains relief.

Functional Improvement (SPADI & DASH Scores)

Shoulder movements and disabilities were assessed through SPADI and DASH scores. According to Table 4, The TSM group had more significant improvement over time in Week 4 SPADI scores compared to SSE group participants (TSM: 35.6 ± 6.8; SSE: 41.2 ± 6.5, p=0.02). SSE participants outperformed TSM participants in SPADI scoring at Week 8 (SSE: 26.1 ± 5.1, TSM: 28.4 ± 5.3, p=0.04). This demonstrates that SSE participants had better long term functional recovery.

As noted in Table 5, Wilcoxon test results for DASH scores also showed in between group significant differences ($p < 0.01$); therefore, both treatments were confirmed to be beneficial for performing noted daily activities. These tendencies are illustrated in Figure 2 in which the bar graphs juxtapose SPADI and DASH scores at the given intervals. It is observed that TSM seems to positively affect short term recovery in function whereas SSE appears to provide better long-term functional outcomes.

Range of Motion (ROM) Outcomes

Active shoulder range of motion (ROM) measurements taken of each participant’s shoulder with a goniometer are available in Table 7. The average and range of active and passive ROM, along with other measurements, are displayed in the table with the circular hypermobility syndrome type figures. Moreover, the SSE group displays significant enhancement in shoulder mobility as measured with AROM and PROM by week 8 (p=0.03 for AROM and p=0.02 for PROM). A remarkable improvement is evident from the continuum of AROM and PROM measurements from the SSE group, which consistently outperform the TSM group as illustrated in Figure 4. These findings support the idea that SSE offers a greater mobility enhancement compared to TSM, especially over longer periods, as SSE focuses on progressive stabilization and mobility training.

Overall Effectiveness: Repeated Measures ANOVA and Interaction Effects

To analyze changes in pain, function and strength at all the aforementioned time points, a Repeated Measures ANOVA was used. The emerging time × group interaction effect patterns are displayed in Table 8 on NPRS, SPADI, DASH scores, and gains in strength, whereby all the above yielded p values of 0.02, 0.01, 0.008, and 0.03. These findings thus support the studies' assertion that both interventions had positive effects on the patients, yet the effects differed temporally.

Thus, the current results demonstrate that TSM and SSE provide suggestions on modifying and enhancing each other in different phases of rehabilitation.

Conclusion

The results derived from the present data supported the alternative hypothesis (H_1) that TSM is more effective in the short-term and acute pain relief as well as initial recovery of function than SSE, in which SSE is superior in the recovery of scapular muscle strength and long-term functional outcome.

Such findings reject the idea that one or the other type of treatment is sufficient by employing the phased treatment model where TSM is used first to reduce pain and make the patient ambulant followed by SSE for the purpose of stabilizing and strengthening them. This integration is in accordance with the biomechanism of the shoulder and thoracic spine using the regional interdependence model.

Limitations of the Study

This research, like any other, has limitations. The study had restricted sample size of 80 participants which may influence the generalizability of the findings. The study was conducted for just eight weeks and therefore cannot analyze long term relapse, or maintainance of functional gains. Moreover, patient compliance to mandated exercises, changes in lifestyle, and previous history of rehabilitation were uncontrolled which could have affected the outcomes. Blinding of subjects was not possible because of the kinds of interventions employed, which is a source of bias.

Implication of the Study

The results of the study have important clinical implications indicating that rehabilitation of patients with SSI should thus involve the two-phase process characterized by the use of TSM in the initial phase to minimize the intensity of symptoms while using SSE in the later phase to enhance the improvement of patients' functional capacity. The results of this study may be beneficial for physiotherapists, orthopedic surgeons, and physiotherapy specialists in order to gain a better systematic approach to developing appropriate interventions for the patients with the shoulder impingement syndrome. However, this investigation also brings into focus scapular movements and thoracic cage involvement as factors that need to be taken into account for the successful rehabilitation of shoulder pathologies, thus, effectively encouraging the 'whole body' approach to treatment.

Future Recommendations

Further studies should look into extended follow up periods to see the treatment effects retention after the eight week period. These research deductions would be better confirmed and their external validity enhanced through larger multi-center trials on more heterogeneous populations. Moreover, research efforts should focus on the combination of TSM and SSE in a single rehabilitation program to investigate which intervention approach, sequential or concurrent, achieves better results. The purpose of this study is to deepen the understanding of effective SSI rehabilitation strategies through the examination of neuromuscular adaptations, exercise adherence, and patient-reported outcomes.

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