RESEARCH PAPER

Effectiveness of Reversal of Antagonist PNF Technique with NMES in Recruitment of VMO during Early Stages of Post ACL Reconstruction Rehabilitation

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ABSTRACT

Introduction: Anterior Cruciate Ligament (ACL) reconstruction is commonly associated with quadriceps inhibition, particularly reduced activation of the Vastus Medialis Oblique (VMO), resulting in extension lag, altered patellar tracking, decreased strength, and delayed functional recovery. Early restoration of VMO recruitment is essential for successful rehabilitation. Reversal of Antagonist Proprioceptive Neuromuscular Facilitation (PNF) techniques combined with Neuromuscular Electrical Stimulation (NMES) may enhance neuromuscular activation and facilitate VMO recruitment during the early stages of post-ACL reconstruction rehabilitation. The present study aimed to determine the effectiveness of Reversal of Antagonist PNF techniques with NMES in improving VMO recruitment and functional outcomes following ACL reconstruction.

Methodology:A randomized controlled trial was conducted on 30 participants (20–45 years) who underwent isolated ACL reconstruction and presented with extension lag during the early postoperative period. Participants were randomly allocated into two groups: a Conventional Rehabilitation Group (n=15) and an Experimental Group (n=15) receiving Reversal of Antagonist PNF techniques combined with NMES in addition to conventional rehabilitation. The intervention duration was six weeks. Outcome measures included Numerical Pain Rating Scale (NPRS), Patellar Tracking Test, Modified Straight Leg Raise (SLR) Test, Manual Muscle Testing (MMT) of quadriceps, knee range of motion, extension lag assessment, and Electromyographic (EMG) analysis of VMO recruitment. Statistical analysis was performed using paired t-tests with significance set at $p<0.05$.

Results:Both groups demonstrated statistically significant improvements in all outcome measures following intervention ($p<0.001$). However, the experimental group showed superior improvements compared to the conventional group. VMO EMG activity increased from 35.2 ± 6.49 %MVIC to 66.7 ± 8.08 %MVIC in the experimental group, compared to 34.2 ± 6.48 %MVIC to 62.0 ± 7.37 %MVIC in the conventional group. Greater improvements were also observed in quadriceps strength, pain reduction, patellar tracking, knee flexion range, extension lag reduction, and functional performance among participants receiving Reversal of Antagonist PNF with NMES.

Conclusion: The findings suggest that Reversal of Antagonist PNF techniques combined with NMES are more effective than conventional rehabilitation alone in enhancing VMO recruitment during the early stages of post-ACL reconstruction rehabilitation. The combined intervention facilitates improved neuromuscular activation, quadriceps strength, patellar stability, and functional recovery, making it a valuable adjunct to conventional ACL rehabilitation protocols..

Keywords: Anterior Cruciate Ligament Reconstruction, Vastus Medialis Oblique, Proprioceptive Neuromuscular Facilitation, Reversal of Antagonist, Neuromuscular Electrical Stimulation, VMO Recruitment, Electromyography, ACL Rehabilitation.

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INTRODUCTION

Knee joint is one of the most complex joints of the human body, it plays a crucial role in carrying out the weight bearing activities. For smooth translation of the human body the gliding, sliding and rotatory components of the knee work in unison, the joints that comprise the knee are the medial and lateral femorotibial joints, and the patellofemoral joint, along with the hinge action of the knee during flexion and extension activities there are few rotatory components which are combined with the flexion and extension activities, there are two important mechanisms that take place during the hinge activities i.e locking during the terminal knee extension and unlocking during the initiation of flexion of the knee**.** The main muscle responsible for the locking to happen is the quadriceps muscle among the group of quadriceps the VMO (Vastus Medialis Oblique) is responsible in the range of terminal knee extension, the main unlocking muscle is the popliteus muscle which initiates flexion torque. Therefore at terminal extension there is anterior glide moment followed by the external rotation of the tibia, during initiation of knee

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flexion there is first medial rotation of tibia followed by posterior glide of the tibia. This is observed during the open kinetic chain movements.

The knee must be extensively stabilized by the body as it has to carry the whole weight of the body in different directions. The stability during movements that is the dynamic stability is provided by the muscles and the stability at rest that is the static stability is provided by the capsule, ligaments, meniscus the non- contractile structures. One of the most vulnerable and chief ligament of the knee joint is the ACL (Anterior Cruciate Ligament), its attachments are the outer part of the medial tibial plateau and the inner aspect of lateral femoral condyle. The ligament itself has two bundles the Anteromedial Bundle (AMB) and the Posterolateral bundle (PLB). The ligament is oriented in cross manner, the ligament is responsible for giving stability against excessive forward movement of tibia with respect to femur, and also extreme ranges of internal rotation of tibia. ACL is highly susceptible to injury, majority of the mechanisms which are responsible are the unbalanced rotatory forces acting on the knee along with the inefficient techniques of landing during the sporting activities, unbalanced muscle forces. This disposes ACL to the unreasonable amount of stress which in turn results into capacitating ACL beyond its threshold which causes rupture of its bundles either it's the intermediate degree rupture or the full degree rupture.

Fluidity of the movement in the knee joint is supervised by the healthy muscle control and balance, followed by the appropriate input regarding the proprioception in the knee joint. There should be balance between the quadriceps and hamstring, claves and the shin muscles. Majority of the cases show us that the quadriceps is pushed into arthrogenic muscle inhibition due to prolonged immobilization which results into specifically reduced girth of the quadriceps and the atrophy of the VMO fibers. There is weakness and tightness of the hamstrings due to non- weightbearing component of the rehabilitative protocol. Most of the times there is overcompensation by the ITB (Iliotibial Band) and gastrocnemeius and soleus muscles. Therefore hyperactivity of these surrounding muscles compensates for the weakness and inhibition of the vastus medialis obliques pushing it into more weaker and inhibitory states, planning for pinpoint activity and facilitation of the VMO is necessary during post ACLR (ACL Reconstruction) rehabilitative procedures. Proprioceptors are the receptors which provide knowledge about the movement of the joint in the space, its gives the brain the directives about the position of the particular bone with regard to the movement expected, resulting into proper angular and directional changes in due course of the movement. These receptors are present in the ligament, capsule, menisci, and tendon of the muscle, these are free nerve endings, ruffini endings, pacinican corpuscles, golgi tendon organ, as stated above, pain sensations, postural reflexes, intra articular pressure, velocity and direction of the movement, acceleration, deceleration, sudden changes in direction, extremes of stress imposed in the joint are all detected and studied and passed forward to the brain, which produces apparent efferent responses from the brain. The post surgical period of ACLR is very crucial, due to inflammatory changes and inclusion of tendon in place of ligament places immense responsibility on the body's immune system to adapt to the following changes, inflammatory reactions seen during the swelling phase results in damage to the mechanoreceptors of the ligament and surrounding structures, therefore proprioceptive input at appropriate time is important. Immediate training of VMO for proper muscle activation and efficient muscle firing is necessary for proper patellar tracking resulting in the smooth flexion and extension activities avoiding patellar maltracking and excessive strain on the patello-femoral joint.

The Reversal of antagonist PNF technique emphasizes on the Sherrington principal, which says that successive excitation of the agonist muscle produces increased contractions of the antagonist muscle, its done isometrically or concentrically in the ranges available further increasing as the range is comfortable to the patient. Therefore by alternately contracting the VMO and the quadriceps group along with hamstrings we might be able to effectively facilitate the VMO. Adding neuromuscular stimulation to the techniques might produce significant stimulus for proper excitation of the VMO, we will use surge faradic current for the stimulation of the fibers of the VMO muscle. Reversal of Antagonist consists of 3 basic techniques 1. Rhythmic initiation, 2. Stabilizing reversals, 3. Dynamic reversals. Rhythmic initiation focuses on the one after other isometric contraction of the VMO and quadriceps with the hamstrings, Stabilizing reversals focuses on the isotonic alternating contractions, where small amplitude of movement is seen, Dynamic reversals consists of alternating concentric contractions with resistance the movement should be fluid without any pause during the regime.

In this study we are amiming to effectively strengthen the VMO in early stages of post surgical recovery where VMO activation is pf utmost importance for better prognosis

MATERIAL AND METHODS

The study protocol was presented for approval in front of the institutional ethical committee and college research protocol committee of institution. After the ethical approval the purpose of the study was explained to the participants, written consent was taken from the participants, They were screened based on the inclusion and exclusion criteria.

Inclusion Criteria

The individuals who belong to the age group between 20 to 45 yrs with isolated ACL reconstruction who are in there day two of postoperative period with extension lag were included in this study.

Exclusion Criteria

The individuals who are having bilateral ACL rupture, Meniscal tears along with other adjuvant structural injury of the knee, Proximal hip joint injuries and distal ankle joint injuries and the individuals who were non cooperative were excluded from the study.

The study was carried out in Krishna Hospital Karad, with a period of 6 months, the Nature of the study was Randomised Control Trial. At first the desired individuals were scanned according to the inclusion and exclusion

criteria, after identifying the desired individuals for the study a brief explanation was given to the individuals regarding the study and what is its purpose. Later written consent was taken from the individuals, Further the individuals were divided into two groups each with 15 individuals, followed by filling the data collection sheet, and analyzation of the individuals according to the outcome measures was done,one group with 15 individuals was administered the experimental protocol for ACLR rehabilitation Consisting of the Reversal of antagonist PNF technique with NMES along with tradition protocol , the second group of 15 individuals were administered with the conventional ACLR rehabilitation protocol, at the end of 6 weeks after completing the intervention, the individuals were again assessed according to the outcome measures. Further the data obtained of pre and post interventional study was statistically analyzed and results were obtained by using INSTAT software. The study was concluded based on the alternative hypothesis.

Ethical Approval and Participant Consent

The Ethical Approval for undertaking the proposed study has been obtained from the Institutional Ethics Committee of Krishna Vishwa Vidyapeeth (Deemed to be University), Karad, Maharashtra, India, with their Letter No. KVV/IEC/02/2026 dated 21st January 2026. Written informed consent was obtained from all the participants, who were assured of confidentiality and their right to withdraw anytime.

Outcome Measure

The interpretation of the study was based on the outcome measures like NPRS, Patella Tracking test, Modified SLR test, MMT for quadriceps, Goniometry Assessment for knee joint flexion and extension, EMG analysis. The study was concluded by the statistical analysis for the same.

CONVENTIONAL ACL REHABILITATION PROTOCOL

Week	Exercises / Intervention	Dosage	Clinical Reasoning
Week 1	MFR to posterior capsule, hamstrings & calf muscles; patellar mobilization; Grade I Mulligan tibial medial rotation; knee press with NMES; assisted terminal knee extension (TKE); heel slides; adductor isometrics; assisted SLR; ankle AROM	MFR 10–15 min; patellar glides 10–15 reps; Mulligan glide 10–15 glides × 3 sets; knee press 10 sec hold × 7–10 reps with NMES (10 sec on/5 sec off); TKE 7–10 reps; heel slides 7–10 reps; adductor isometrics 10 sec × 10 reps; assisted SLR 5–7 reps; ankle AROM 10 reps each	Improves soft tissue mobility, patellar gliding, knee ROM, VMO activation, proprioception and early quadriceps recruitment.
Week 2	Continue Week 1 + tabletop (90–90) knee flexion ROM; unassisted TKE; resisted ankle ROM; clam shells; side SLR; core activation with pelvic bridging	MFR 10 min; NMES knee press 10 sec × 10 reps (10 sec on/3 sec off); tabletop flexion 10 reps; TKE 10 reps; heel slides 7–10 reps; ankle ROM with green band 10 reps; clam shells 10 reps; side SLR 5–7 reps; bridging 7–10 reps	Progresses VMO strengthening, improves knee ROM with gravity assistance, enhances hip stability, pelvic control and core activation.
Week 3	Continue Week 2 + stretching (calf, hamstring, adductors); resisted heel slides; manual resistance to TKE; independent SLR; resisted clam shells	Stretching 10 sec × 3 sets; resisted heel slides 7–10 reps; TKE with manual resistance 10 reps; SLR without assistance 7 reps; resisted clam shells 10 reps	Enhances flexibility, knee control, hip strength, proprioception and functional quadriceps activation.
Week 4	Continue previous exercises + swiss ball knee extensions; resisted TKE and side SLR (0.5 kg cuff); dynamic quads; heel raises; calf raises on thera disc; hamstring curls; standing VMO activation	Stretching 20 sec × 2 sets; tabletop flexion 10 reps; knee extensions 5 sec × 7 reps; resisted exercises 10 reps; dynamic quads 10 reps; heel raises/calf raises/hamstring curls 7–10 reps; standing VMO activation 10 sec × 7 reps	Progressive resistance improves muscle strength and functional quadriceps activation. Weight-bearing activities improve neuromuscular control.
Week 5	Continue Week 4 + quadruped cat-camel and bird-dog exercises; mini squats (30–40°)	Cat-camel 10 reps; bird-dog 5 reps each side; mini squats 7–10 reps	Improves proprioception, trunk stability, gluteal strength and functional knee control during stair activities.
Week 6	Continue Week 5 + sit-to-stand with swiss ball assistance; step-up and step-down training (10 cm block)	Sit-to-stand 10 reps; step-up/step-down 10 reps forward & backward	Enhances functional mobility, stair climbing ability, balance, coordination and closed-chain knee control.

Experimental ACL Rehabilitation Protocol

Week	Exercises / Intervention	Dosage	Clinical Reasoning

Week 1	MFR to posterior capsule, hamstrings & calf muscles; patellar mobilization; Grade I Mulligan tibial medial rotation; assisted terminal knee extension (TKE); heel slides; adductor isometrics; assisted SLR; ankle AROM; **rhythmic stabilization with irradiation for knee flexion and extension**	MFR 10–15 min; patellar glides 10–15 reps; Mulligan glide 10–15 glides × 3 sets; TKE 7–10 reps; heel slides 7–10 reps; adductor isometrics 10 sec × 10 reps; assisted SLR 5–7 reps; ankle AROM 10 reps each; **resistance to knee extension provided by theraband and resistance to knee flexion provided by therapist**	Improves soft tissue mobility, patellar gliding, knee ROM, VMO activation, proprioception and early quadriceps recruitment. **Rhythmic stabilization initiates movement through alternating knee flexion and extension, causing activation of the agonist by excitation of the antagonist.**
Week 2	Continue Week 1 + tabletop (90–90) knee flexion ROM; unassisted TKE; resisted ankle ROM; clam shells; side SLR; core activation with pelvic bridging; rhythmic stabilization with irradiation for knee flexion and extension	MFR 10 min; tabletop flexion 10 reps; TKE 10 reps; heel slides 7–10 reps; ankle ROM with green band 10 reps; clam shells 10 reps; side SLR 5–7 reps; bridging 7–10 reps; resistance to knee extension provided by theraband and resistance to knee flexion provided by therapist	Progresses VMO strengthening, improves knee ROM with gravity assistance, enhances hip stability, pelvic control and core activation. Rhythmic stabilization helps in movement initiation through alternating knee flexion and extension, activating the agonist by excitation of the antagonist.
Week 3	Continue Week 2 + stretching (calf, hamstring, adductors); resisted heel slides; manual resistance to TKE; independent SLR; resisted clam shells; **stabilizing reversals for knee flexion and extension with surge faradic current**	Stretching 10 sec × 3 sets; resisted heel slides 7–10 reps; TKE with manual resistance 10 reps; SLR without assistance 7 reps; resisted clam shells 10 reps; **knee extension resistance provided by theraband and knee flexion resistance provided by therapist**	Enhances flexibility, knee control, hip strength, proprioception and functional quadriceps activation. **Partial range knee flexion and extension is targeted with alternating action and no pause in between; excitation of antagonist helps activation of agonist.**
Week 4	Continue previous exercises + swiss ball knee extensions; resisted TKE and side SLR (0.5 kg cuff); dynamic quads; heel raises; calf raises on thera disc; hamstring curls; standing VMO activation; stabilizing reversals for knee flexion and extension with surge faradic current	Stretching 20 sec × 2 sets; tabletop flexion 10 reps; knee extensions 5 sec × 7 reps; resisted exercises 10 reps; dynamic quads 10 reps; heel raises/calf raises/hamstring curls 7–10 reps; standing VMO activation 10 sec × 7 reps; knee extension resistance provided by theraband and knee flexion resistance provided by therapist	Progressive resistance improves muscle strength and functional quadriceps activation. Weight-bearing activities improve neuromuscular control. Partial range knee flexion and extension is targeted with alternating action and no pause in between; excitation of antagonist helps activation of agonist.
Week 5	Continue Week 4 + quadruped cat-camel and bird-dog exercises; mini squats (30–40°); **dynamic reversals (slow reversals and slow reversal hold) for knee flexion and extension with surge faradic current**	Cat-camel 10 reps; bird-dog 5 reps each side; mini squats 7–10 reps; slow reversals with alternating movement without hold in targeted achieved ROM; **resistance for knee extension provided by theraband and resistance for knee flexion provided by therapist; slow reversal hold with 5–7 sec hold at end of movement followed by alternating action**	Improves proprioception, trunk stability, gluteal strength and functional knee control during stair activities. **Dynamic reversals strengthen the agonist by excitation of the antagonist in the achieved full range.**
Week 6	Continue Week 5 + sit-to-stand with swiss ball assistance; step-up and step-down training (10 cm block); dynamic reversals (slow reversals and slow reversal hold) for knee flexion and	Sit-to-stand 10 reps; step-up/step-down 10 reps forward & backward; slow reversals with alternating movement without hold in targeted achieved ROM; resistance for knee extension provided by theraband and	Enhances functional mobility, stair climbing ability, balance, coordination and closed-chain knee control. Dynamic reversals strengthen the agonist by excitation of the antagonist in the achieved full range.

	extension with surge faradic current	resistance for knee flexion provided by therapist; slow reversal hold with 5–7 sec hold at end of movement followed by alternating action	

RESULTS

1. Conventional Group NPRS Pre-Intervention And Post-Intervention

Table1 A-

Conventional group NPRS		
Pre-intervention NPRS	**Frequency**	**Percentage**
4	5	33%
5	7	46.60%
6	3	20%

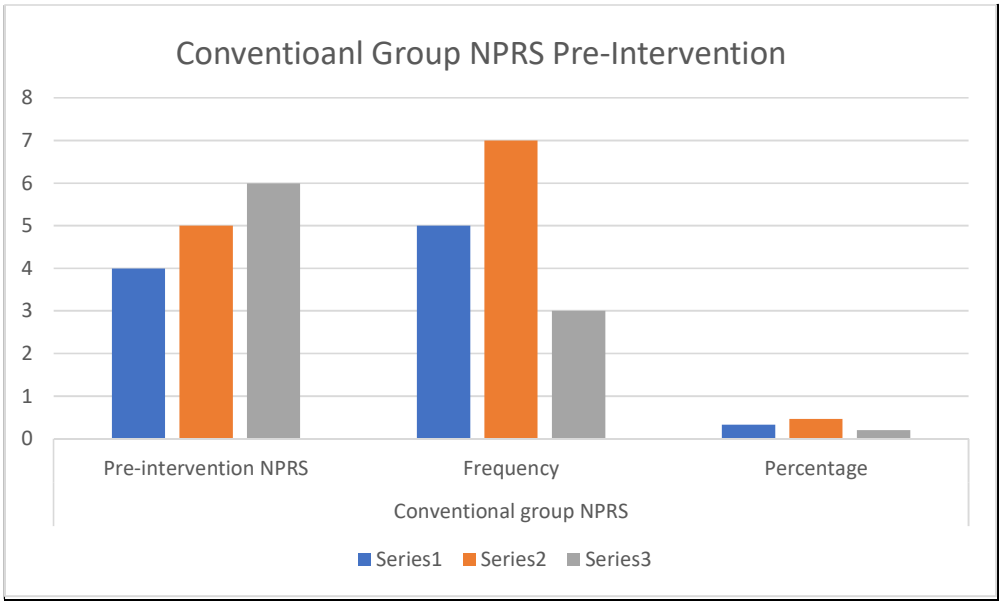


Fig 1 A –

Table 1 B

Conventional Group NPRS		
Post-intervention NPRS	**Frequency**	**Percentage**
2	2	13.30%
3	7	46.60%
4	6	40%

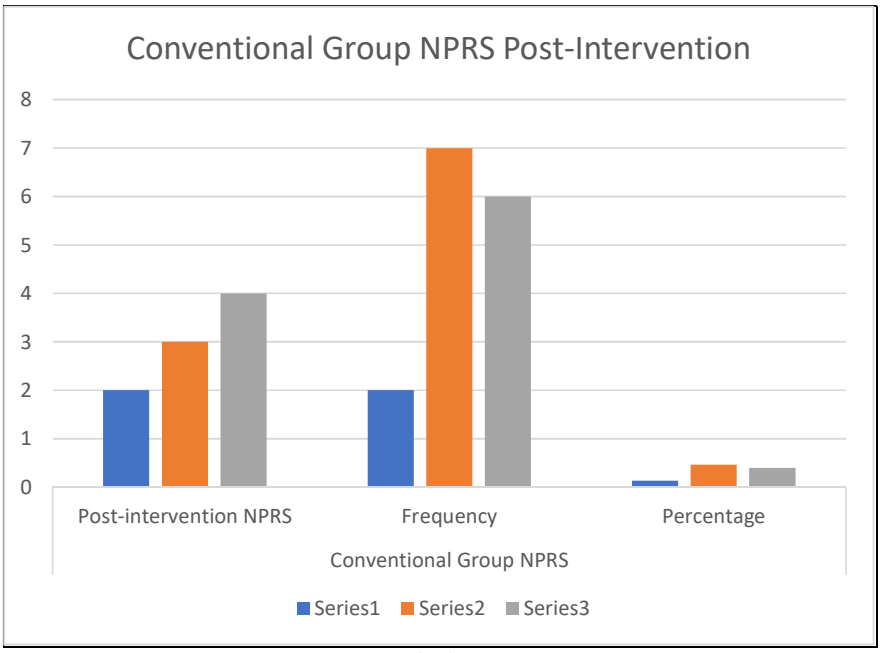


Fig 1 B

2. Experimental Group Pre and Post interventional NPRS

Table 2A-

Experimental Group NPRS		
Pre-intervention NPRS	**Frequency**	**Percentage**
4	4	26.60%
5	5	33.30%
6	6	40%

Fig 2 A-

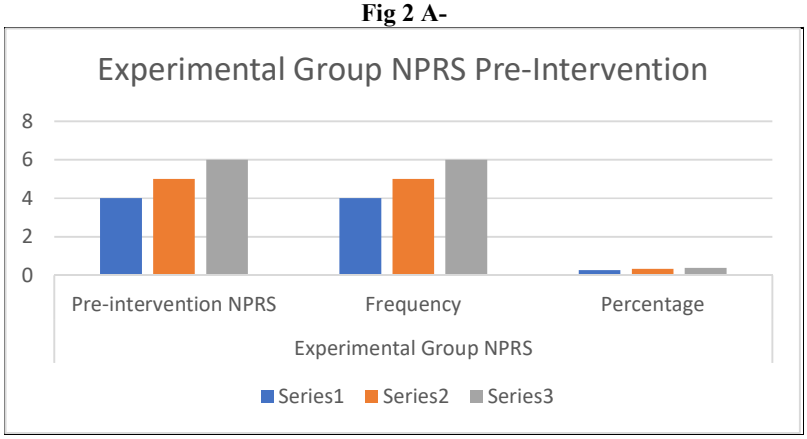
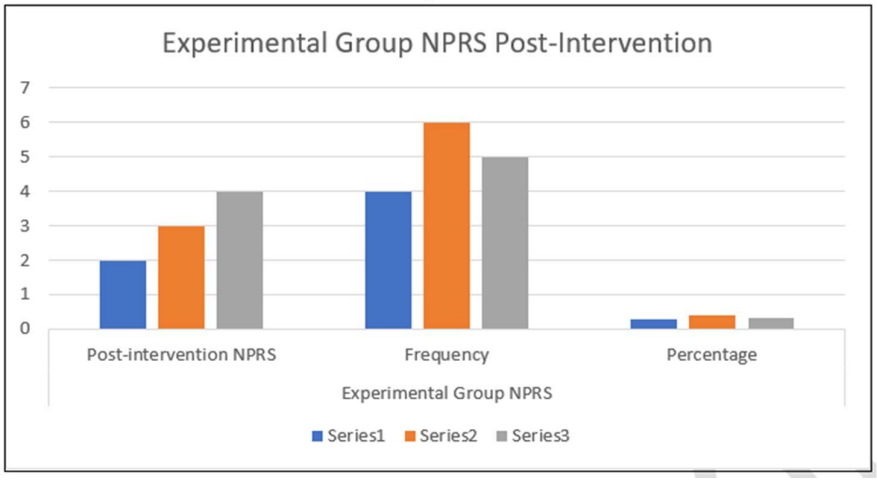


Table 2B-

Experimental Group NPRS		
Post-intervention NPRS	**Frequency**	**Percentage**
2	4	26.60%
3	6	40%
4	5	33.30%

Fig 2B-



Interpretation-

NPRS PRE AND POST INTERVENTIONAL ANALYSIS						
Group	**Pre-test Mean**	**Pre test SD**	**Post-Test Mean**	**Post-test SD**	**t-value**	**p-value**
Conventional	4.87	± 0.74	3.27	± 0.70	5.87	<0.001
Experimental	5.13	± 0.83	3.07	± 0.80	5.22	<0.001

Both conventional and experimental groups showed statistically significant reduction in pain following intervention. However, the experimental group showed greater reduction in NPRS scores, indicating better pain management with the addition of Reversal of Antagonist PNF technique and NMES.

Table 3A-

3. Conventional Group Patellar Tracking Test Pre And Post Intervention

The following grades have been followed for recording the patellar tracking, 0- normal tracking, 1- mild maltracking, 2- moderate malracking.

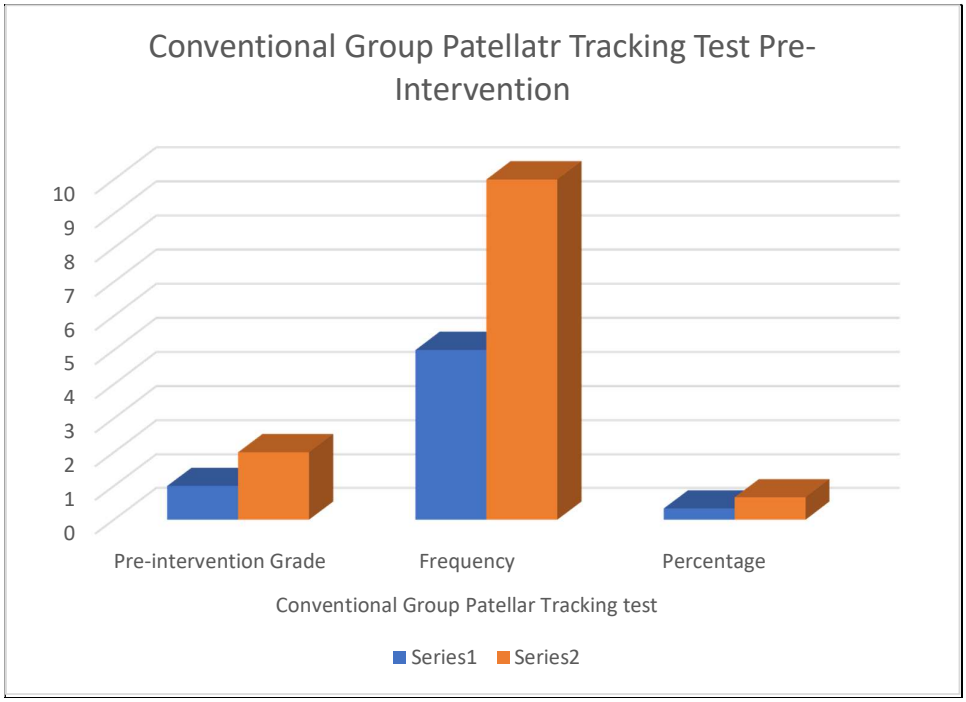
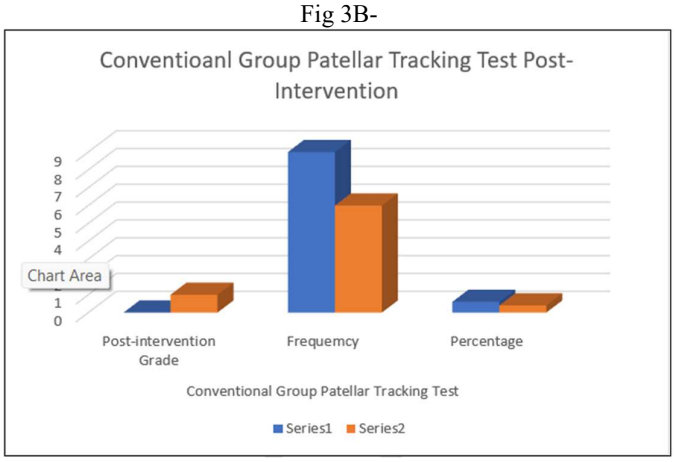


Fig 3A-

Table 3B-

Conventional Group Patellar Tracking Test		
Post-intervention Grade	**Frequency**	**Percentage**
0	9	60%
1	6	40%

Fig 3B-



4. Experimental Group Patellar Tracking Test Pre And Post Intervention.

Table 4A-

Experimental Group Patellar Tracking Test		
Pre-intervention Grade	**Frequency**	**Percentage**
1	5	33.30%
2	10	66.60%

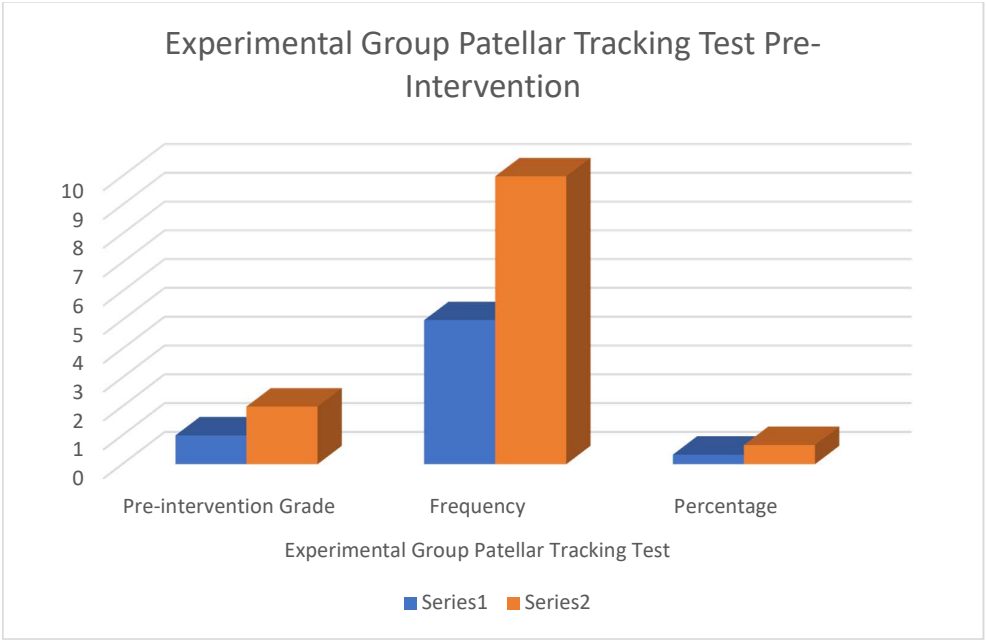


Fig 4A-

Table 4B-

Experimental Group Patellar Tracking Test		
Post-Intervention Grade	**Frequency**	**Percentage**

0	9	60%
1	6	40%

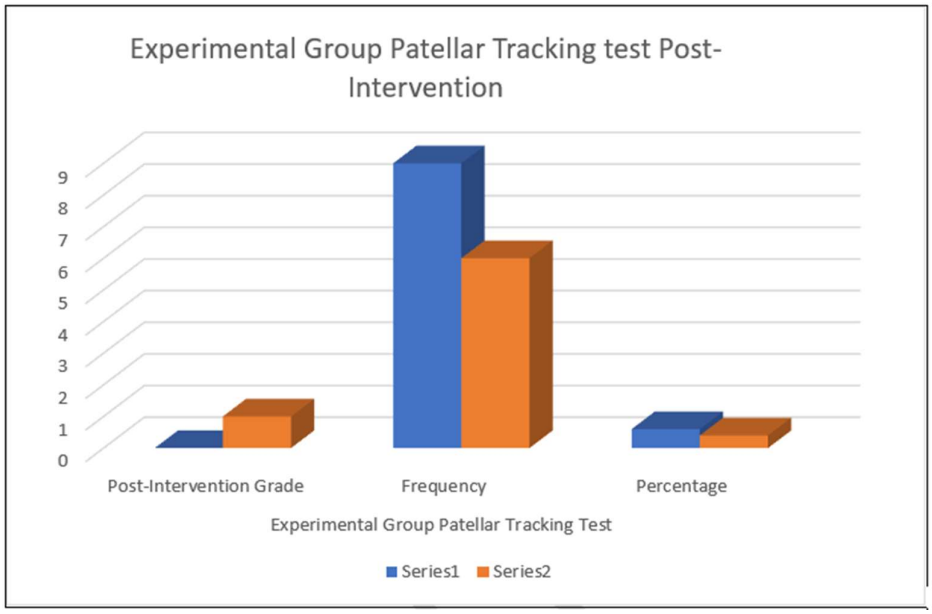


Fig 4B-

Interpretation-

PATELLAR TRACKING TEST PRE AND POST INTERVENTIONAL ANALYSIS						
Group	**Pre-test Mean**	**Pre test SD**	**Post-Test Mean**	**Post-test SD**	**t-value**	**p-value**
Conventional	1.67	± 0.49	0.4	± 0.51	5.55	<0.001
Experimental	1.67	± 0.49	0.4	± 0.51	6.14	<0.001

Both conventional and experimental groups showed statistically significant improvement in patellar tracking. The experimental group demonstrated slightly greater improvement, suggesting enhanced quadriceps control and patellar alignment following the combined PNF-NMES intervention.

5. Conventional Group Pre and Post Intervention Modified SLR test.

The following grades have been used to record the modified SLR test, 0-unable to perform SLR,1- Performs SLR but unable to hold for 10 seconds, 2- holds 10 sec with extension lag/ tremors, 3-holds 10 sec without extension lag/ tremors.

Table 5A-

Conventional Group Modified SLR test		
Pre-Intervention Grade	**Frequency**	**Percentage**
0	10	66.60%
1	5	33.30%

Fig 5A-

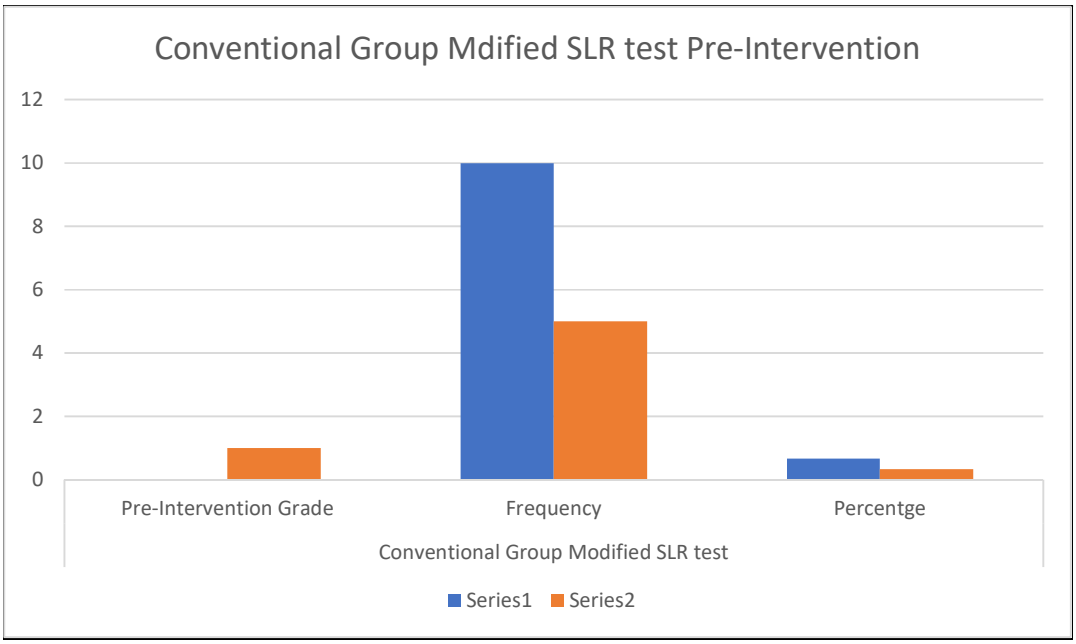
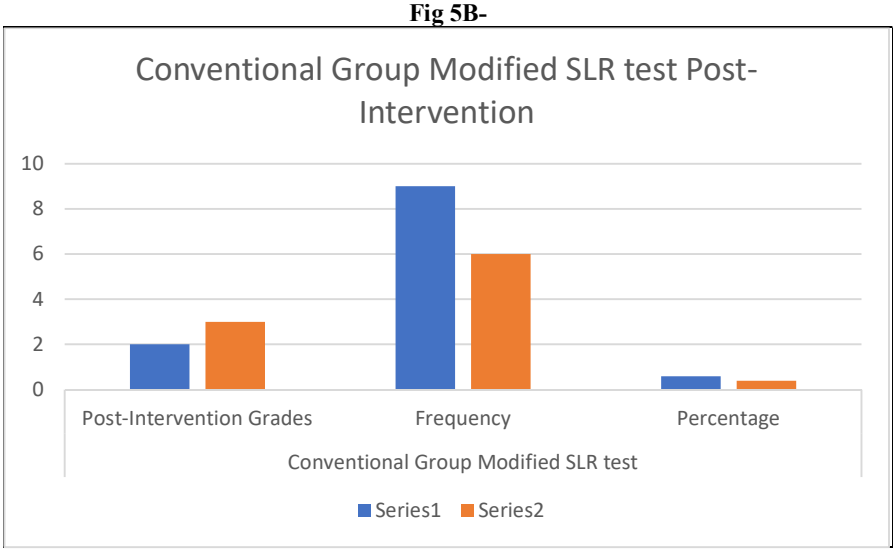


Table 5B-

Conventional Group Modified SLR test		
Post-Intervention Grades	**Frequency**	**Percentage**
2	9	60%
3	6	40%

Fig 5B-



6. Experimental Group Pre And Post Intervention Modified SLR test.

Table 6A-

Experimental Group Modified SLR Test		
Pre-Intervention Grades	**Frequency**	**Percentage**
0	8	53.30%
1	7	46.60%

Fig 6A-

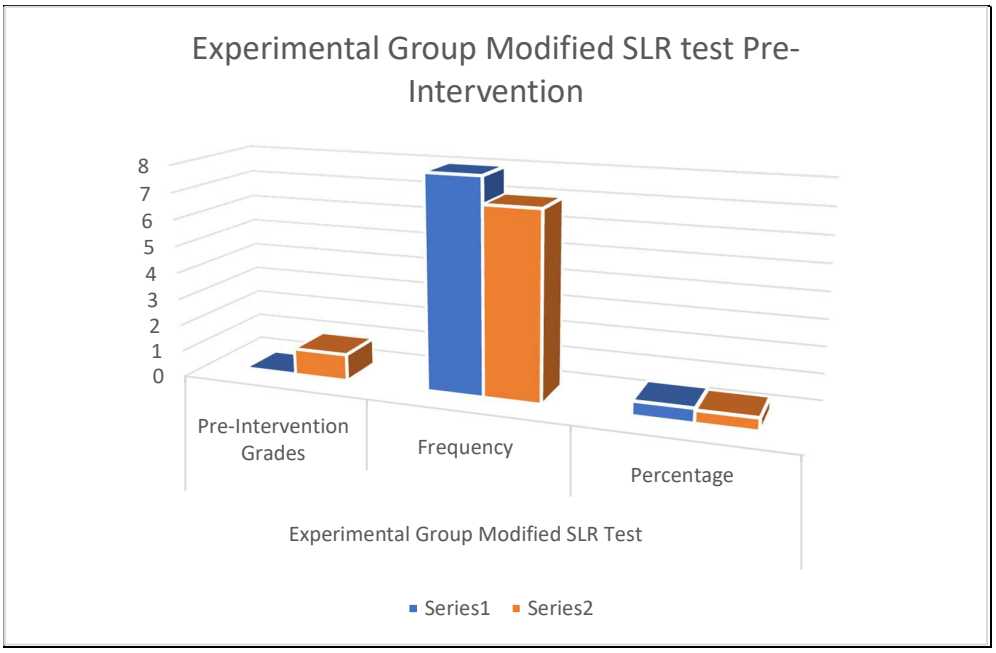
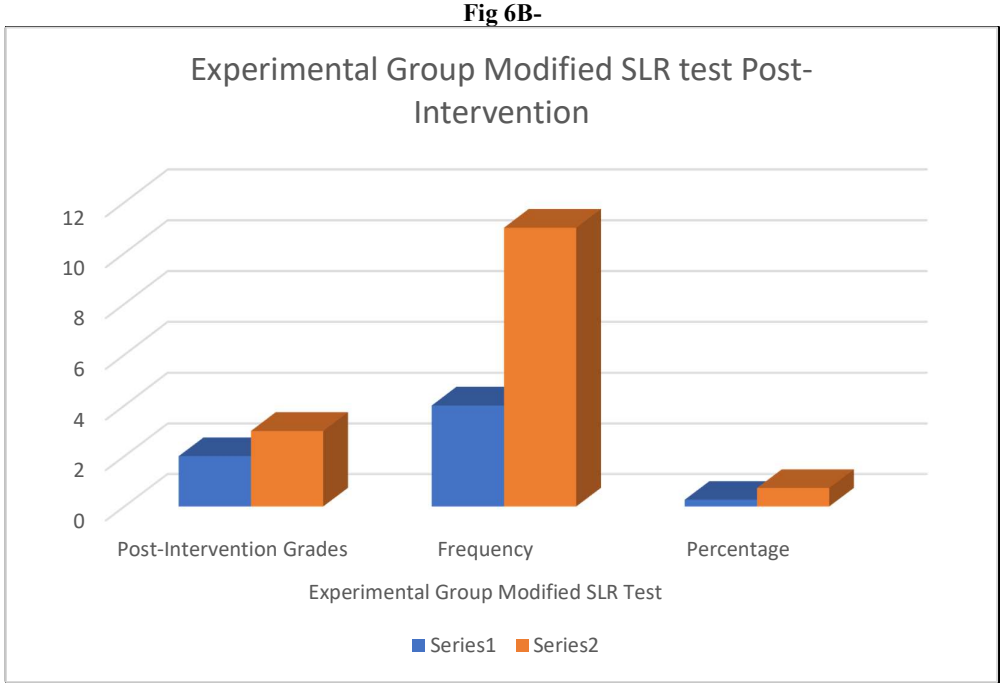


Table 6B-

Experimental Group Modified SLR Test		
Post-Intervention Grades	**Frequency**	**Percentage**
2	4	26.60%
3	11	73.30%

Fig 6B-



Interpretation –

MODIFIED STRAIGHT LEG SLR PRE AND POST INTERVENTIONAL ANALYSIS

Group	Pre-test Mean	Pre test SD	Post-Test Mean	Post-test SD	t-value	p-value
Conventional	0.33	± 0.49	2.4	± 0.51	11.37	<0.001
Experimental	0.47	± 0.52	2.73	± 0.46	10.99	<0.001

Both groups demonstrated statistically significant improvement in SLR performance. The experimental group achieved higher post-test scores, indicating superior VMO activation and improved quadriceps recruitment.

7. Conventional Group Pre and Post Intervention Quadriceps MMT.

Table 7A-

Conventional Group Quadriceps MMT		
Pre-Intervention Grades	**Frequency**	**Percentage**
1	7	46.60%
2	8	53.30%

Fig 7A-

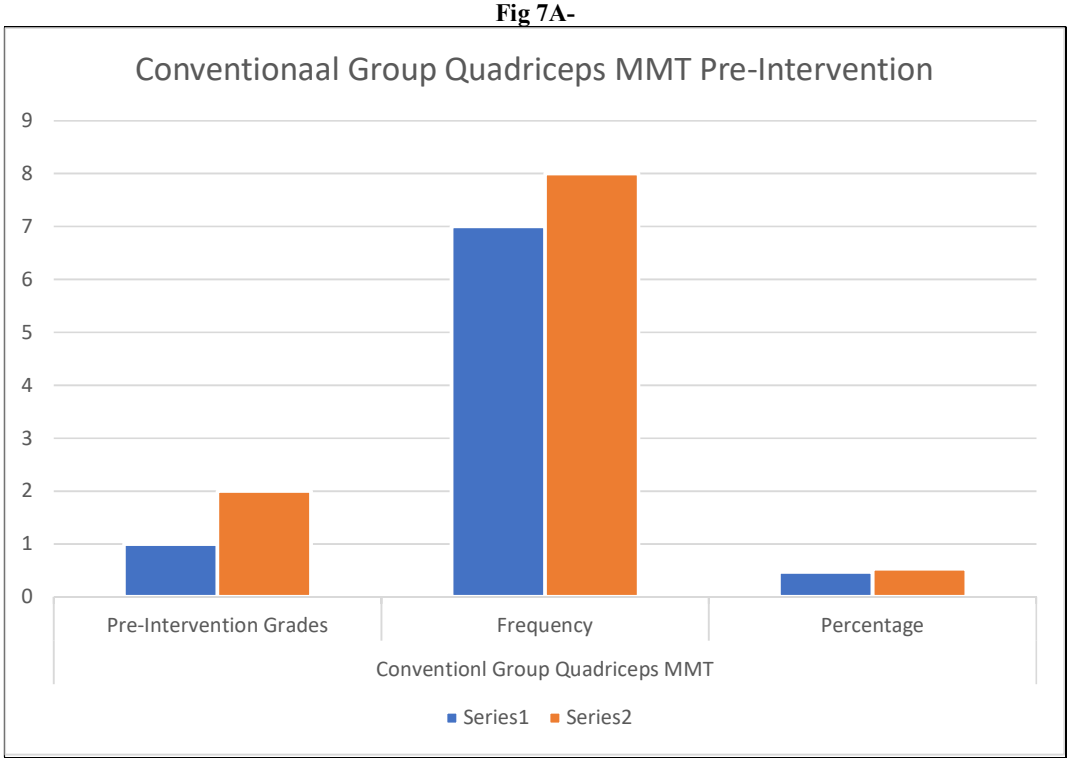
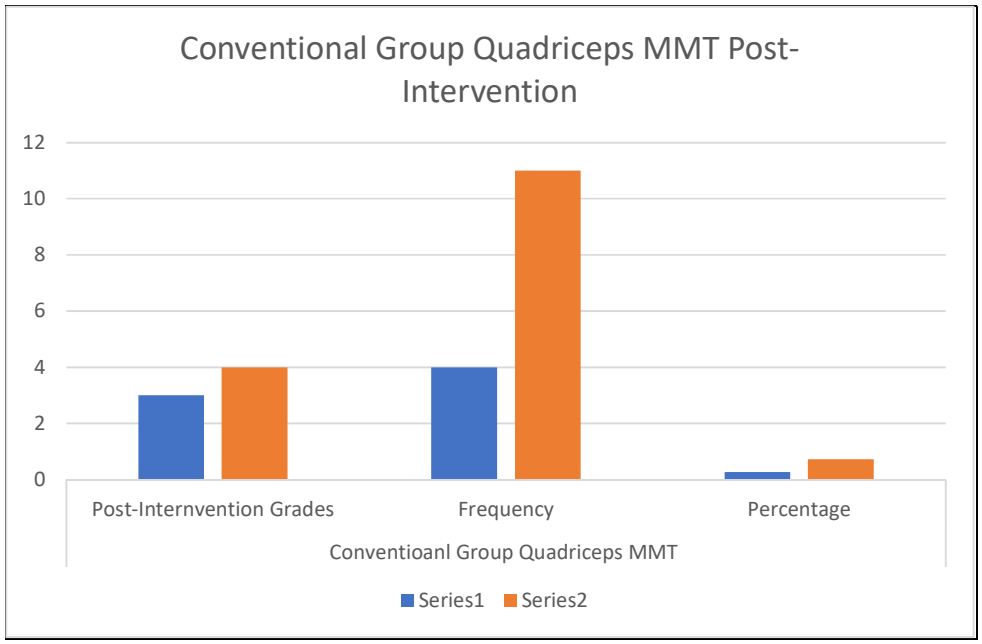


Table 7B-

Conventional Group Quadriceps MMT		
Post-Intervention Grades	**Frequency**	**Percentage**
3	4	26.60%
4	11	73.30%

Fig 7B-



8. Experimental Group Pre and Post Intervention Quadriceps MMT.

Table 8A-

Experimental Group Quadriceps MMT		
Pre-Interventional Grades	**Frequency**	**Percentage**
1	9	60%
2	6	40%

Fig 8A-

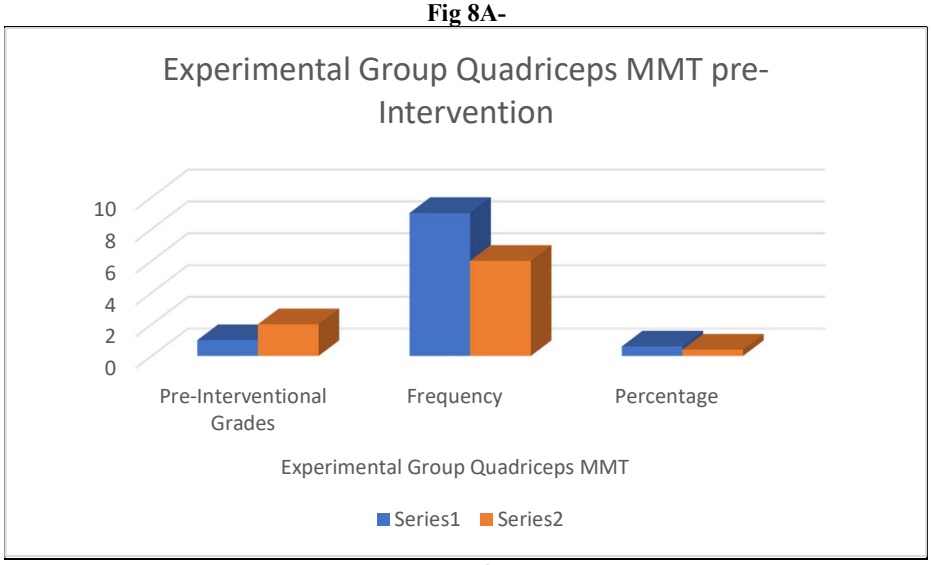
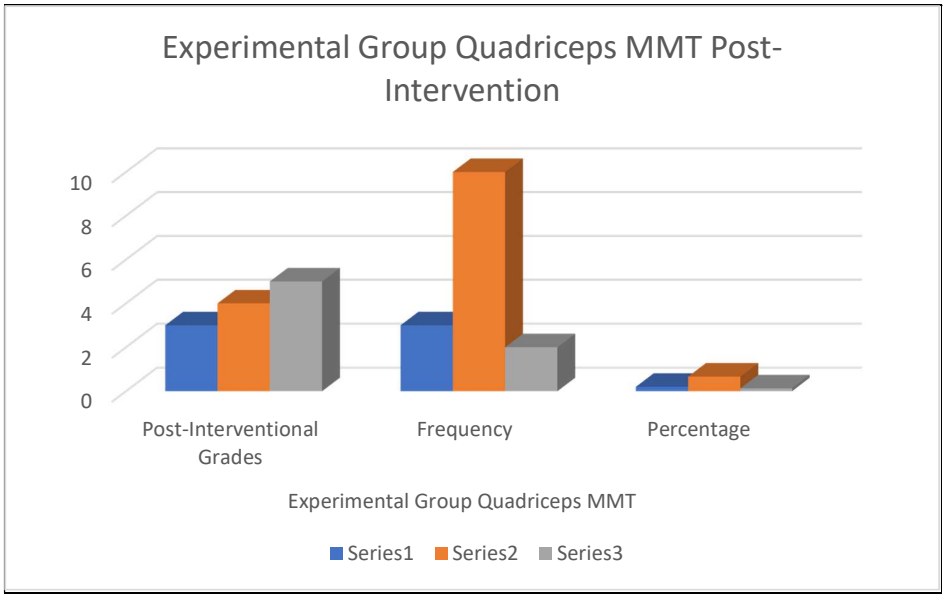


Table 8B-

Experimental Group Quadriceps MMT		
Post-Interventional Grades	**Frequency**	**Percentage**
3	3	20%
4	10	66.60%
5	2	13.30%

Fig 8B-

MANNUAL MUSLCE TESTING FOR QUADRICEPS PRE AND POST INTERVENTIONAL ANALYSIS						
Group	**Pre-test Mean**	**Pre test SD**	**Post-Test Mean**	**Post-test SD**	**t-value**	**p-value**
Conventional	1.53	± 0.52	3.73	± 0.46	15.2	<0.001
Experimental	1.4	± 0.51	3.93	± 0.59	10.72	<0.001



Interpretation –

Significant improvement in quadriceps strength was observed in both groups. The experimental group showed better post-intervention muscle strength, supporting the effectiveness of Reversal of Antagonist PNF with NMES in improving VMO recruitment.

9. Conventional Group Pre and Post Interventional Knee Flexion Range.

Table 9A-

Conventional Group Knee Flexion Rnge		
Pre-Interventional Range	**Frequency**	**Percentage**
38	1	6.60%
40	1	6.60%
45	5	33.30%
50	2	13.30%
52	1	6.60%
55	2	6.60%
60	1	6.60%
62	1	6.60%
66	1	6.60%

Fig 9A-

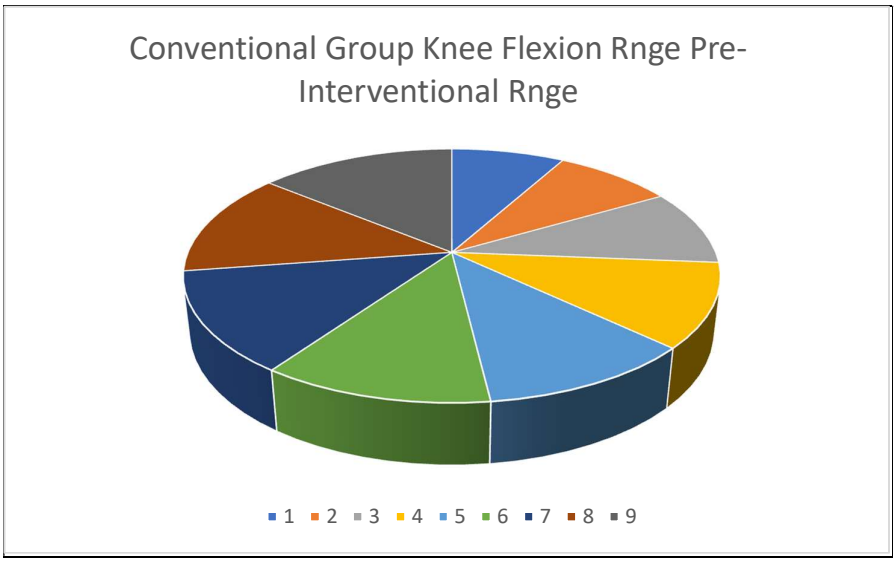
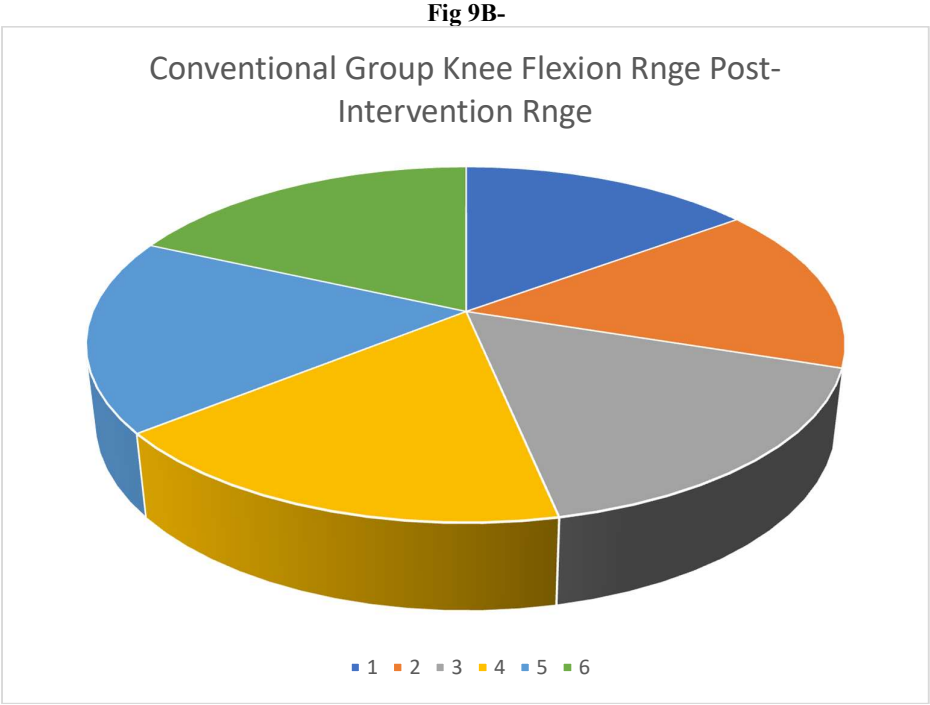


Table 9B-

Conventional Group Knee Flexion Rnge		
Post-Intervention Range	**Frequency**	**Percentage**
98	2	13.30%
100	6	40%
110	2	13.30%
115	1	6.60%
116	1	6.60%
120	3	20%

Fig 9B-



10. Experimental Group Pre and Post Knee Flexion Ranges.

Table 10A-

Experimental Group Knee Flexion Range

Pre-Intervention Range	Frequency	Percentage
45	4	26.60%
46	1	6.60%
48	1	6.60%
50	1	6.60%
52	4	26.60%
55	1	6.60%
60	1	6.60%
62	1	6.60%
66	1	6.60%

Fig 10 A-

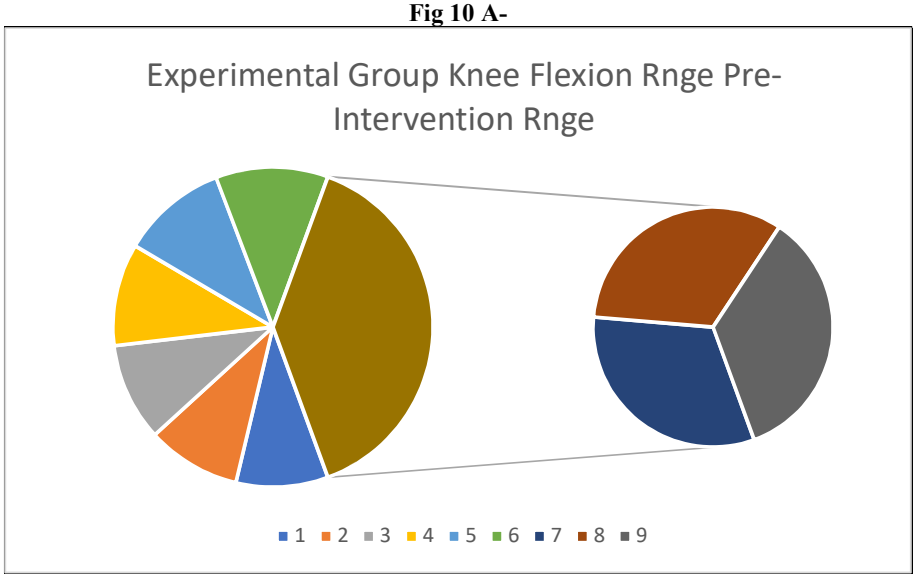
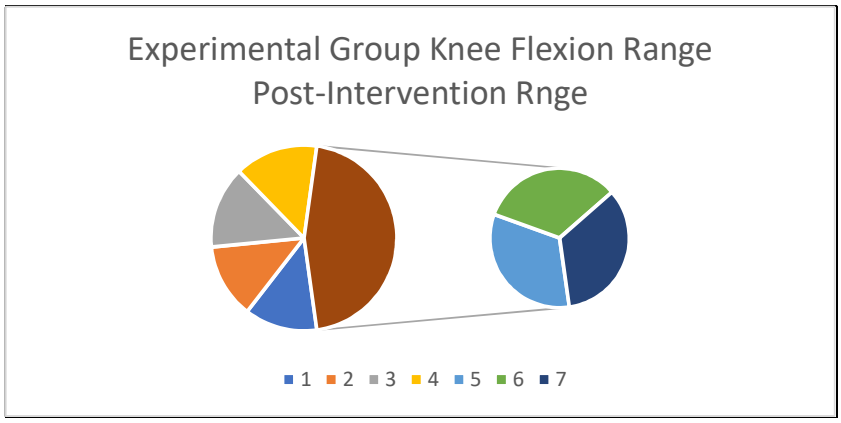


Table 10 B-

Experimental Group Knee Flexion Range		
Post-Intervention Range	**Frequency**	**Percentage**
98	2	13.30%
100	5	33.30%
110	2	13.30%
112	1	6.60%
115	2	13.30%
116	1	6.60%
120	2	13.30%

Fig 10 B-



Interpretation-

KNEE FLEXION RANGE OF MOTION PRE AND POST INTERVENTION ANALYSIS						
Group	**Pre-test Mean**	**Pre test SD**	**Post-Test Mean**	**Post-test SD**	**t-value**	**p-value**
Conventional	50.2	± 8.12	107.13	± 8.97	20.43	<0.001
Experimental	51.67	± 6.65	107.6	± 8.42	21.09	<0.001

Both groups demonstrated significant improvement in knee flexion ROM after intervention. The experimental group showed slightly greater improvement, indicating better functional recovery.

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11. Conventional Group Knee Extension Lag Pre and Post Intervention

Table 11 A-

Conventional Group Extension Lag		
Pre-Intervention Lag	**Frequency**	**Percentage**
7	3	20%
10	7	46.60%
12	2	13.30%
15	3	20%

Fig 11A-

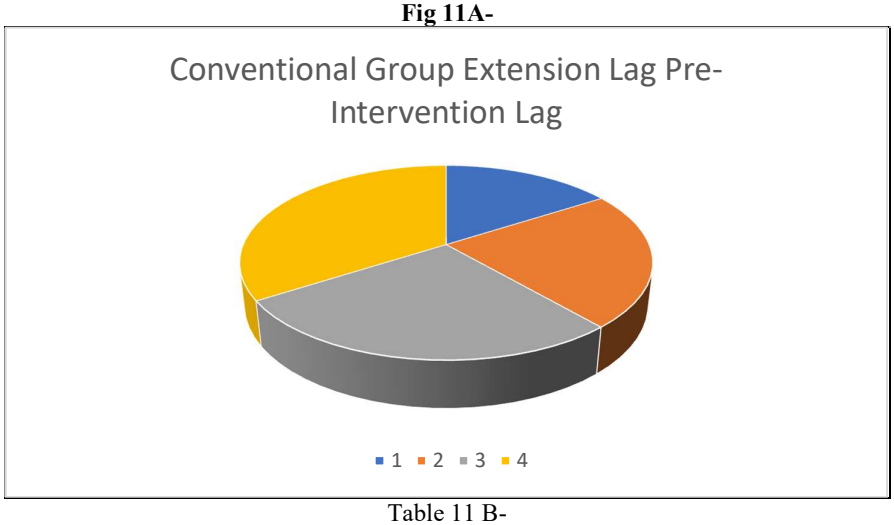
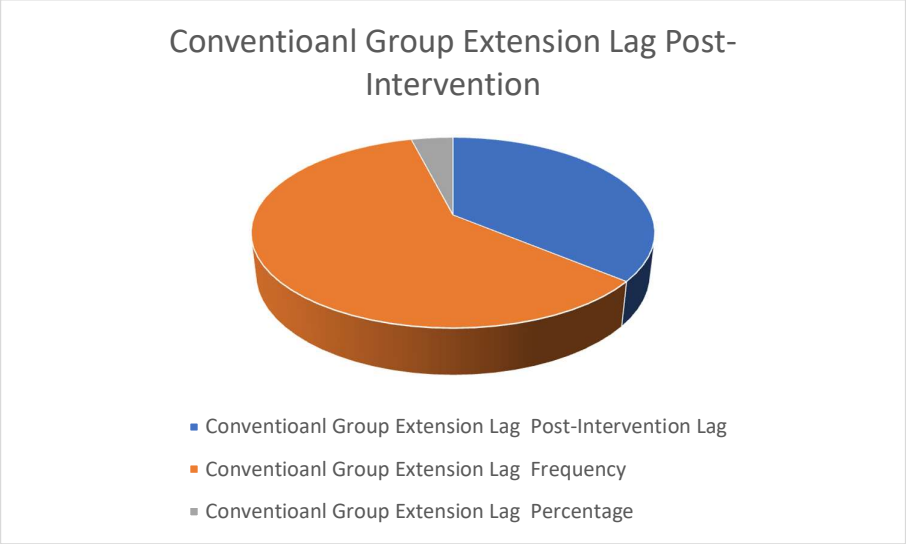


Table 11 B-

Conventioanl Group Extension Lag		
Post-Intervention Lag	**Frequency**	**Percentage**
3	5	33.30%
5	7	46.60%
8	3	20%

Fig 11B-



12. Experimental Group Pre and Post Intervention Knee Extension Lag.

Table 12 A-

Experimental Group Extension Lag		
Pre-Intervention Lag	**Frequency**	**Percentage**
7	**4**	**26.60%**
10	**4**	**26.60%**
12	**3**	**20%**
14	**1**	**6.60%**
15	**3**	**20%**

Fig 12 A-

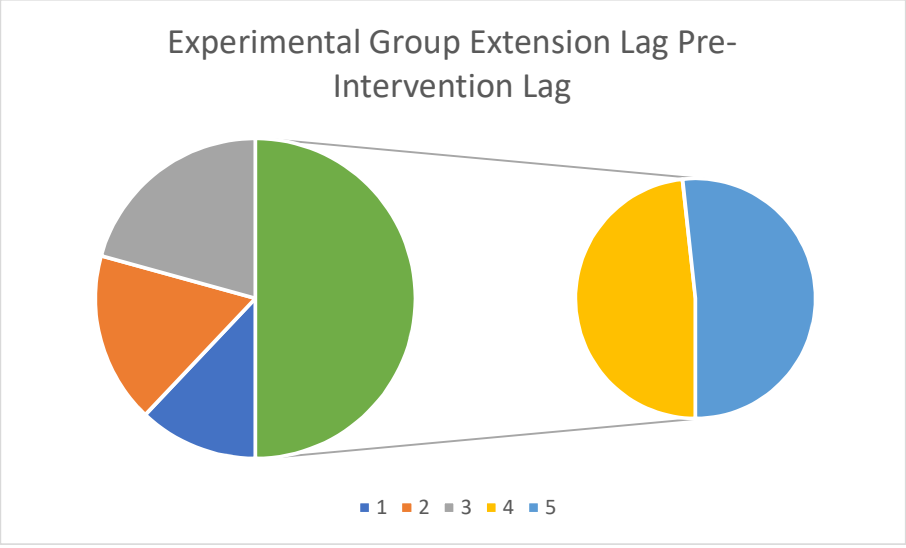
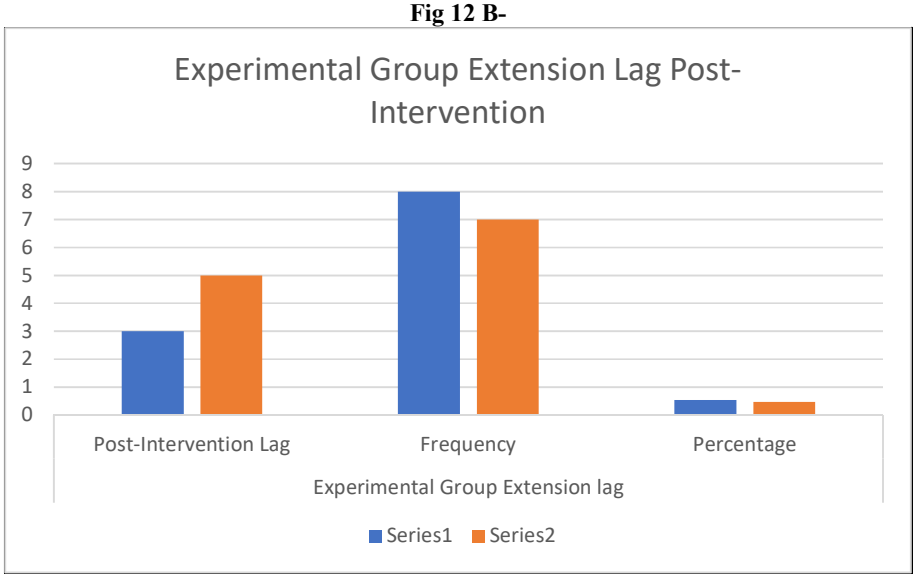


Table 12 B-

Experimental Group Extension lag		
Post-Intervention Lag	**Frequency**	**Percentage**
3	**8**	**53.30%**
5	**7**	**46.60%**

Fig 12 B-



Interpretation

KNEE EXTENSION LAG RANGE PRE AND POST INTERVENTION ANALYSIS						
Group	**Pre-test Mean**	**Pre test SD**	**Post-Test Mean**	**Post-test SD**	**t-value**	**p-value**
Conventional	**10.67**	**± 2.72**	**4.93**	**± 1.83**	**6.51**	**<0.001**
Experimental	**10.87**	**± 3.02**	**3.93**	**± 1.03**	**8.4**	**<0.001**

A statistically significant reduction in extension lag was observed in both groups. The experimental group showed greater reduction, indicating improved quadriceps activation and knee control.

13. Conventional Group Pre and Post EMG analysis

Table 13 A-

Conventional Group EMG Analysis		
Pre-Intervention EMG MIVC%	Frequency	Percentage
24	1	6.60%
26	1	6.60%
27	1	6.60%
29	1	6.60%
30	1	6.60%
31	1	6.60%
33	1	6.60%
34	1	6.60%

35	1	6.60%
37	1	6.60%
38	1	6.60%
39	1	6.60%
41	1	6.60%
43	1	6.60%
46	1	6.60%

Fig 13 A-

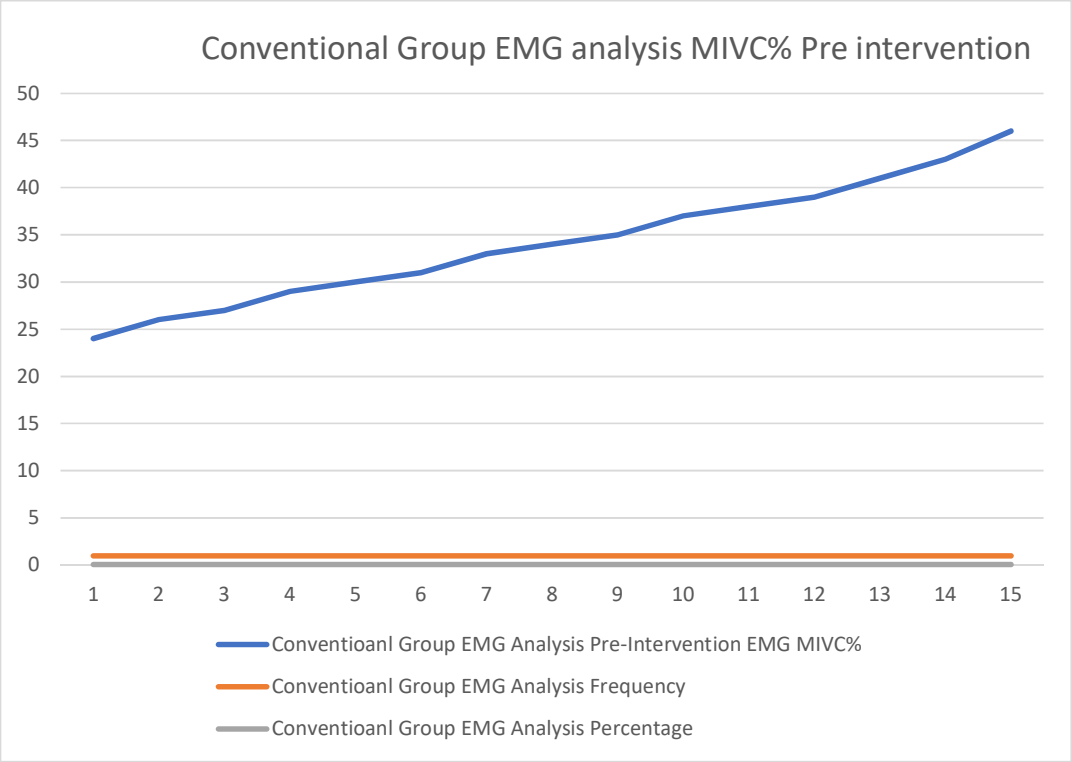


Table 13 B-

Conventional Group EMG Analysis		
Post-Intervention EMG MIVC%	**Frequency**	**Percentage**
50	**1**	**6.6**
53	**1**	**6.6**
55	**1**	**6.6**
56	**1**	**6.6**
57	**1**	**6.6**
58	**1**	**6.6**
60	**1**	**6.6**
61	**1**	**6.6**
63	**1**	**6.6**
64	**1**	**6.6**
67	**1**	**6.6**
69	**1**	**6.6**

71	**1**	**6.6**
72	**1**	**6.6**
74	**1**	**6.6**

Fig 13 B-

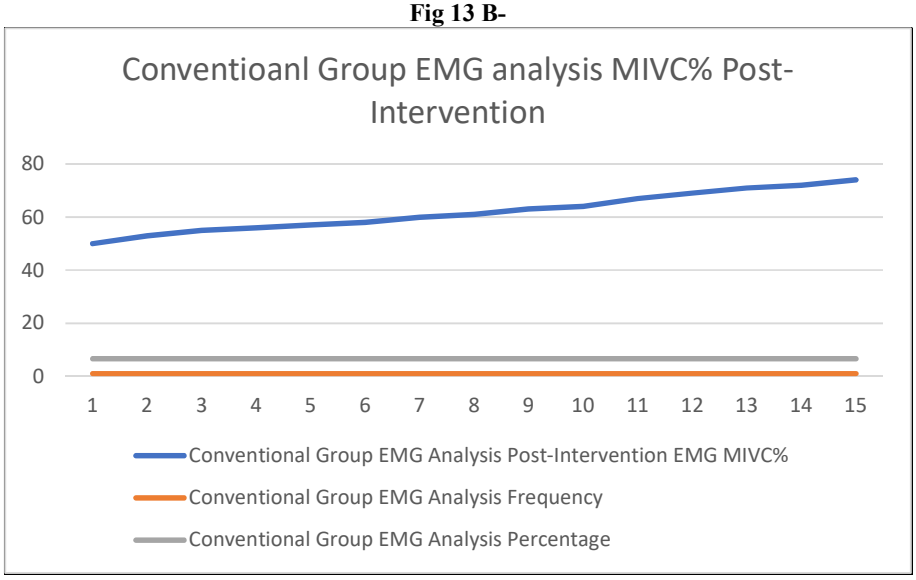


Table 13 C-

PRE AND POST INTERVENTION EMG ANALYSIS FOR CONVENTIONAL GROUP		
EMG	**Mean (%MVIC)**	**Standard Deviation (SD)**
Pre-Intervention EMG	**34.2**	**6.48**
Post-Intervention EMG	**62**	**7.37**
Difference (%MVIC)	**27.8**	**1.82**

The post-intervention EMG analysis demonstrated improved normalized VMO recruitment during quadriceps setting exercises following 6 weeks of conventional ACL rehabilitation. Increased variability in recruitment values among participants may reflect individual differences in neuromuscular recovery and quadriceps activation capacity.

The mean normalized EMG activity of the VMO during quadriceps setting improved from 34.2 ± 6.48 %MVIC pre-intervention to 62.0 ± 7.37 %MVIC post-intervention following 6 weeks of conventional ACL reconstruction rehabilitation. Mean improvement in VMO recruitment was 27.8 ± 1.82 %MVIC.

14. Experimental Group Pre and Post Intervention EMG analysis

Table 14 A-

Experimental Group EMG Analysis		
Pre-Intervention EMG MIVC%	**Frequency**	**Percentage**
25	1	6.60%
27	1	6.60%
28	1	6.60%
30	1	6.60%
31	1	6.60%

32	1	6.60%
34	1	6.60%
35	1	6.60%
36	1	6.60%
38	1	6.60%
39	1	6.60%
40	1	6.60%
42	1	6.60%
44	1	6.60%
47	1	6.60%

Fig 14 A-

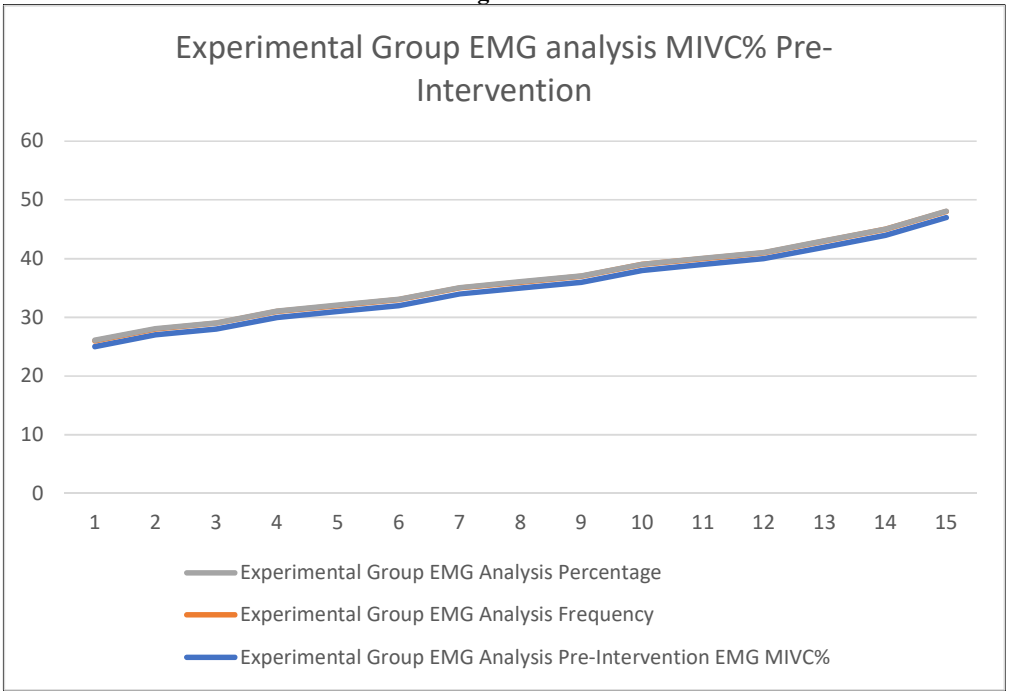


Table 14 B-

Experimental Group EMG analysis		
Post-Intervention EMG MIVC%	**Frequency**	**Percentage**
55	1	6.60%
57	1	6.60%
59	1	6.60%
60	1	6.60%
61	1	6.60%
63	1	6.60%
64	1	6.60%
66	1	6.60%
67	1	6.60%
69	1	6.60%
72	1	6.60%
74	1	6.60%
76	1	6.60%

78	1	6.60%
80	1	6.60%

Fig 14 B-

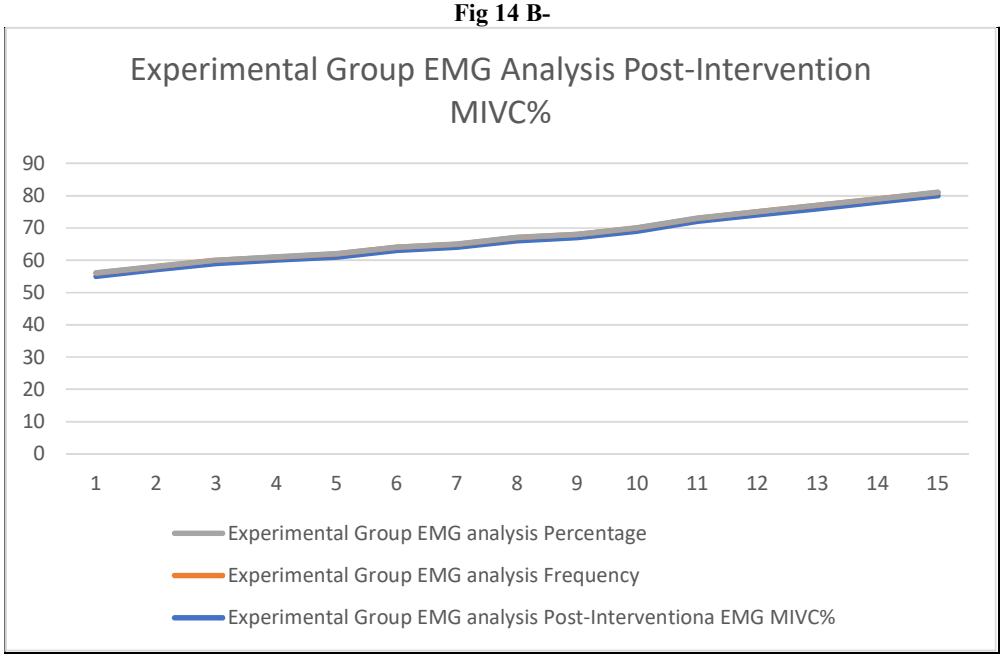


Table 14 C-

PRE AND POST EMG ANALYSIS FOR EXPERIMENTAL GROUP		
EMG	**Mean (%MVIC)**	**Standard Deviation (SD)**
Pre-Intervention EMG	35.2	6.49
Post-Intervention EMG	66.7	8.08
Difference (%MVIC)	31.5	2.18

Participants receiving the experimental rehabilitation protocol consisting of Reversal of Antagonist PNF technique with NMES demonstrated notable improvement in normalized VMO recruitment following 6 weeks of ACL reconstruction rehabilitation, reflecting enhanced neuromuscular activation and quadriceps recruitment capacity.

The experimental group demonstrated an increase in normalized VMO EMG activity from 35.2 ± 6.49 %MVIC pre-intervention to 66.7 ± 8.08 %MVIC post-intervention following 6 weeks of rehabilitation using Reversal of Antagonist PNF technique with NMES. Mean improvement in VMO recruitment was 31.5 ± 2.18 %MVIC.

The findings of the study demonstrate that both conventional rehabilitation and Reversal of Antagonist PNF technique combined with NMES were effective in improving pain, quadriceps strength, VMO recruitment, patellar tracking, knee ROM, and functional performance in individuals during the early stages of ACL reconstruction rehabilitation.

However, the experimental group consistently demonstrated greater improvements across most outcome measures when compared to the conventional group. These findings suggest that the addition of Reversal of Antagonist PNF technique with NMES enhances neuromuscular facilitation, improves VMO recruitment, reduces pain and extension lag, and promotes faster functional recovery following ACL reconstruction.

DISCUSSION

The present randomized controlled trial was conducted to determine the effectiveness of Reversal of Antagonist Proprioceptive Neuromuscular Facilitation (PNF) technique combined with Neuromuscular Electrical Stimulation (NMES) on Vastus Medialis Oblique (VMO) recruitment during the early stages of anterior cruciate ligament (ACL) reconstruction rehabilitation. The findings of the study demonstrated significant improvements in both

the conventional rehabilitation group and the experimental group; however, the experimental group consistently showed superior outcomes in terms of VMO recruitment, quadriceps strength, pain reduction, patellar tracking, knee range of motion, and functional performance.

Following ACL reconstruction, arthrogenic muscle inhibition commonly affects the quadriceps muscle, particularly the VMO, resulting in reduced muscle activation, extension lag, altered patellar tracking, and delayed functional recovery. Early restoration of VMO activity is therefore considered essential for successful rehabilitation. The rationale behind incorporating Reversal of Antagonist PNF was based on Sherrington's principle of successive induction, whereby activation of antagonist muscles facilitates stronger recruitment of agonist muscles. When combined with NMES, additional sensory and motor stimulation may further enhance neuromuscular activation and motor unit recruitment.

Pain levels measured using the Numerical Pain Rating Scale (NPRS) improved significantly in both groups after six weeks of intervention. The conventional group showed a reduction from 4.87 ± 0.74 to 3.27 ± 0.70, whereas the experimental group improved from 5.13 ± 0.83 to 3.07 ± 0.80. Although both interventions were effective in reducing pain, the greater reduction observed in the experimental group suggests that improved neuromuscular control and muscle activation may have contributed to decreased stress on the knee joint and enhanced functional recovery.

Patellar tracking demonstrated significant improvement in both groups. However, participants receiving Reversal of Antagonist PNF with NMES showed slightly better outcomes. Proper activation of the VMO is known to play a critical role in maintaining medial stabilization of the patella. Improved VMO recruitment may therefore have contributed to better patellar alignment and reduced risk of patellofemoral dysfunction during rehabilitation.

The Modified Straight Leg Raise (SLR) test showed marked improvement following intervention. The experimental group achieved higher post-treatment scores compared to the conventional group, indicating superior quadriceps control and ability to maintain active knee extension. Since successful performance of the SLR depends largely on adequate quadriceps activation and minimal extension lag, these findings suggest enhanced neuromuscular recruitment in participants receiving the combined PNF-NMES intervention.

Quadriceps muscle strength assessed using Manual Muscle Testing (MMT) also improved significantly in both groups. The experimental group demonstrated slightly higher post-intervention strength scores, with some participants achieving Grade 5 muscle strength. This improvement may be attributed to the facilitation effects of Reversal of Antagonist PNF techniques, which encourage repeated activation of agonist and antagonist muscle groups, thereby improving motor unit recruitment and neuromuscular efficiency. The addition of NMES likely further enhanced muscle fiber recruitment during voluntary contractions.

Knee flexion range of motion improved substantially in both groups over the six-week rehabilitation period. The experimental group demonstrated marginally greater gains compared to the conventional group. Improved quadriceps activation and reduced pain may have enabled participants to perform therapeutic exercises more effectively, thereby facilitating restoration of knee mobility. Early achievement of adequate knee flexion is important for performing daily activities and progressing toward advanced rehabilitation phases.

Similarly, knee extension lag decreased significantly in both groups. The experimental group demonstrated a greater reduction in extension lag, indicating improved ability of the quadriceps muscle to achieve terminal knee extension. Restoration of full knee extension is one of the primary goals during early ACL rehabilitation, as persistent extension deficits can negatively affect gait mechanics, functional performance, and long-term outcomes. Enhanced VMO recruitment through PNF and NMES may have contributed to the superior improvements observed in the experimental group.

The most important finding of the present study was the improvement observed in electromyographic (EMG) activity of the VMO muscle. The conventional group demonstrated an increase in normalized VMO activity from 34.2 ± 6.48 %MVIC to 62.0 ± 7.37 %MVIC, with a mean improvement of 27.8 ± 1.82 %MVIC. In contrast, the experimental group improved from 35.2 ± 6.49 %MVIC to 66.7 ± 8.08 %MVIC, with a mean improvement of 31.5 ± 2.18 %MVIC. These findings indicate that both rehabilitation approaches were effective in improving VMO recruitment; however, the addition of Reversal of Antagonist PNF with NMES resulted in greater neuromuscular activation of the VMO muscle. This enhanced recruitment is clinically important because adequate VMO activation contributes to improved patellar tracking, quadriceps strength, and overall knee joint stability.

The findings of the present study are consistent with previous literature suggesting that PNF techniques enhance neuromuscular facilitation through proprioceptive stimulation and improved motor learning. Likewise, NMES has been shown to counteract quadriceps inhibition following ACL reconstruction by recruiting muscle fibers that may not be activated during voluntary contractions alone. The combination of these two interventions appears to provide an additive effect, resulting in improved VMO activation and functional recovery.

Overall, the results suggest that incorporating Reversal of Antagonist PNF techniques with NMES into early ACL reconstruction rehabilitation may accelerate recovery of quadriceps function and VMO recruitment. Enhanced muscle activation during the critical early postoperative period may contribute to improved knee stability, reduced extension lag, better patellar tracking, and faster progression toward functional independence.

CONCLUSION

The findings of this study indicate that while both conventional rehabilitation and the experimental intervention were effective in improving clinical outcomes following ACL reconstruction, the addition of Reversal of Antagonist PNF technique with NMES produced greater

improvements in VMO recruitment, quadriceps strength, pain reduction, knee range of motion, patellar tracking, and extension lag. Therefore, Reversal of Antagonist PNF combined with NMES can be considered an effective adjunct to conventional rehabilitation for enhancing VMO activation during the early stages of post-ACL reconstruction recovery

REFERENCE

1. Ba A, Db A. Impact of Proprioceptive Neuromuscular Facilitation (PNF) Techniques on the Range Of Motion (ROM) and Quality Of Life (QOL) In Individuals Who Have Undergone ACL Ligament Reconstruction Surgery.
2. Duman I, Taskaynatan MA, Mohur H, Tan AK. Assessment of the impact of proprioceptive exercises on balance and proprioception in patients with advanced knee osteoarthritis. Rheumatology international. 2012 Dec;32(12):3793-8.
3. Diracoglu D, Aydin R, Baskent A, Celik A. Effects of kinesthesia and balance exercises in knee osteoarthritis. JCR: Journal of Clinical Rheumatology. 2005 Dec 1;11(6):303-10.
4. Ojoawo AO, Olaogun MO, Hassan MA. Comparative effects of proprioceptive and isometric exercises on pain intensity and difficulty in patients with knee osteoarthritis: a randomised control study. Technology and Health Care. 2016 Nov;24(6):853-63.
5. Guede-Rojas F, Benavides-Villanueva A, Salgado-González S, Mendoza C, Arias-Álvarez G, Soto-Martínez A, Carvajal-Parodi C. Effect of strength training on knee proprioception in patients with knee osteoarthritis: A systematic review and meta-analysis. Sports medicine and health science. 2024 Jun 1;6(2):101-10.
6. Choi SA, Cynn HS, Yoon TL, Choi WJ, Lee JH. Effects of ankle dorsiflexion on vastus medialis oblique and vastus lateralis muscle activity during straight leg raise exercise with hip external rotation in patellofemoral pain syndrome. Journal of Musculoskeletal Pain. 2014 Sep 1;22(3):260-7.
7. Shields RK, Madhavan S, Gregg E, Leitch J, Petersen B, Salata S, Wallerich S. Neuromuscular control of the knee during a resisted single-limb squat exercise. The American journal of sports medicine. 2005 Oct;33(10):1520-6.
8. Buckthorpe M, Gokeler A, Herrington L, Hughes M, Grassi A, Wadey R, Patterson S, Compagnin A, La Rosa G, Della Villa F. Optimising the early-stage rehabilitation process post-ACL reconstruction. Sports Medicine. 2024;54(1):49-72.
9. Kochman M, Kasprzak M, Kielar A. ACL reconstruction: Which additional physiotherapy interventions improve early-stage rehabilitation? A systematic review. International journal of environmental research and public health. 2022 Nov 29;19(23):15893.
10. Buckthorpe M. Recommendations for Movement Re training After ACL Reconstruction. Sports Medicine. 2021 Aug 1;51(8):1601-18.
11. Rambaud AJ, Neri T, Dingenen B, Parker D, Servien E, Gokeler A, Edouard P. The modifying factors that help improve anterior cruciate ligament reconstruction rehabilitation: a narrative review. Annals of Physical and Rehabilitation Medicine. 2022 Jun 1;65(4):101601.
12. Asadkarmi S, Zolaktaf V, Taheri H, Eshraghi R. The effect of PNF exercises with a biopsychosocial approach on pain and range of motion after ACL reconstruction.
13. Padasala M, Sharmila B, D'Onofrio R, Bhatt J. Multidisciplinary physiotherapy rehabilitation after anterior cruciate ligament reconstruction: A systematic review. Ita. J. Sports Reh. Po. 2025; 12 (33); 2; 3;-2996-3051; IBSN 007-11119-55; CGIJ OAJI 0.201; Published Online.:3.
14. Ba A, Db A. Impact of Proprioceptive Neuromuscular Facilitation (PNF) Techniques on the Range Of Motion (ROM) and Quality Of Life (QOL) In Individuals Who Have Undergone ACL Ligament Reconstruction Surgery.
15. Al-Abaeje M. Case study of Physiotherapy Treatment of a Patient after ACL Surgery.
16. Engle RP, Canner GG. Proprioceptive neuromuscular facilitation (PNF) and modified procedures for anterior cruciate ligament (ACL) instability. Journal of Orthopaedic & Sports Physical Therapy. 1989 Dec;11(6):230-6.
17. Wang B, Zhang Q, Li P, Xu Y, Li W, Lei X, Wan K, Lu L, Gao X, Zhang S, Fu P. Isokinetic muscle strength training combined with proprioceptive neuromuscular facilitation for rehabilitation of patients after anterior cruciate ligament reconstruction: a protocol for a randomised controlled trial. BMJ open. 2025 Feb 1;15(2):e096036.
18. Zhang W, Zhang D, Liu J. The effect of Proprioceptive Neuromuscular Facilitation (PNF) therapy on functional recovery in patients with knee joint injury: a systematic review and meta-analysis. BMC Musculoskeletal Disorders. 2025 Dec 17.
19. Buckthorpe M, La Rosa G, Della Villa F. Restoring knee extensor strength after anterior cruciate ligament reconstruction: a clinical commentary. International Journal of Sports Physical Therapy. 2019 Feb;14(1):159.
20. Kisner C, Colby LA, Borstad J. Therapeutic exercise:

foundations and techniques. Fa Davis; 2017 Oct 18 .