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Effect of Surged Electrical Muscle Stimulator on Subjects with ACL Reconstruction

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ABSTRACT

Background: Anterior cruciate ligament (ACL) reconstruction is a common orthopedic procedure, often followed by muscle atrophy and pain during the rehabilitation process. This study aims to investigate the effectiveness of surge electrical muscle stimulation (EMS) on muscle recovery, pain reduction, and functional outcomes in individuals post-ACL reconstruction.

Methods: An experimental design was employed with 20 participants aged 18 to 50, who had undergone ACL reconstruction. Participants were randomly assigned to two groups: Group A received surge EMS in tandem with a structured rehabilitation protocol, while Group B underwent the rehabilitation protocol alone. EMS was administered for 20–30 minutes, three times per week for six weeks. Outcomes were assessed using Manual Muscle Testing (MMT) for strength and the Numerical Pain Rating Scale (NPRS) for pain levels at baseline, mid-intervention, and post-intervention.

Results: Group A exhibited a significant increase in MMT scores from 2.33 ± 0.60 to 4.73 ± 0.44 ($p < 0.001$) and a reduction in NPRS scores from 8.73 ± 1.12 to 1.60 ± 1.08 ($p < 0.001$). In contrast, Group B showed improvements in MMT scores from 2.26 ± 0.77 to 3.47 ± 0.50 ($p = 0.0002$) and NPRS scores from 8.40 ± 1.08 to 4.13 ± 0.81 ($p < 0.001$). Although both groups demonstrated improvements, the enhancements in Group A were more pronounced.

Conclusion: The findings indicate that surge EMS significantly enhances muscle strength and reduces pain in individuals undergoing ACL reconstruction when combined with a structured rehabilitation protocol. This study emphasizes the potential of integrating EMS into post-surgical rehabilitation to optimize recovery outcomes and facilitate a quicker return to activities. Further research is warranted to explore long-term effects and the precise application of EMS in this context.

INTRODUCTION

The anterior cruciate ligament (ACL) is a band of dense connective tissue that courses from the femur to the tibia. The ACL is a key structure in the knee joint, as it resists anterior tibial translation and rotational loads. When the knee is extended, the ACL has a mean length of 32 mm and a width of 7-12 mm The ACL, or anterior cruciate ligament, is one of the key ligaments in the knee joint. It plays a crucial role in stabilizing the knee during movements that involve twisting or changing direction, such as running, jumping, and cutting.The ACL is located within the knee joint, connecting the femur (thighbone) to the tibia (shinbone). It runs diagonally in the center of the knee.

Composition: Like other ligaments, the ACL is made up of strong, fibrous tissue called collagen. This tissue provides stability and strength to the knee joint.

The primary function of the ACL is to prevent excessive forward movement of the tibia relative to the femur and to resist rotational forces that could otherwise destabilize the knee joint. It works in conjunction with other ligaments, muscles, and tendons to maintain joint stability.

An ACL (anterior cruciate ligament) injury typically occurs due to a sudden twisting or hyperextension of the knee. This can happen during various activities, including sports like soccer, basketball, football, skiing, or even simple activities like stepping off a curb awkwardly.

The mechanism of injury often involves:

Non-contact movements: Most ACL injuries occur without direct contact from another person or object. A common scenario is when an individual abruptly changes direction, pivots, or lands from a jump with their knee in a position of hyperextension or excessive rotation.

Direct impact: While less common, ACL injuries can also result from a direct impact to the knee, such as a collision with another player in sports like football or rugby.

Twisting motions: Sudden twisting motions of the knee, especially when the foot is planted and the body rotates forcefully, can put significant stress on the ACL and lead to injury.

Hyperextension: When the knee joint is forced beyond its normal range of motion, it can strain or tear the ACL. This can occur during activities like landing from a jump with the knee locked or overextending the knee during a sudden stop.

Arthroscopic ACL (anterior cruciate ligament) surgery is a minimally invasive surgical procedure performed to repair a torn ACL in the knee. The ACL is one of the major ligaments in the knee that helps stabilize it during movement. When the ACL is torn due to injury or trauma, it can result in instability and limited function of the knee joint.

During arthroscopic ACL surgery, small incisions are made around the knee, and a tiny camera called an arthroscope is inserted into one of the incisions. This allows the surgeon to visualize the inside of the knee joint on a monitor. Small surgical instruments are then inserted through other incisions to repair or reconstruct the torn ACL.

Depending on the extent of the injury, the surgeon may either repair the torn ligament or reconstruct it using a graft, which can be taken from the patient's own tissue (autograft) or from a donor (allograft). Common autograft options include the patellar tendon, hamstring tendon.

Arthroscopic ACL surgery offers several advantages over traditional open surgery, including smaller incisions, less tissue damage, reduced pain, faster recovery times, and potentially improved outcomes. However, it is still a major surgical procedure that requires appropriate post-operative rehabilitation and adherence to a structured recovery plan to optimize outcomes and minimize the risk of complications.

ACL rehabilitation has undergone considerable changes over the past decade. Intensive research into the biomechanics of the injured and the operated knee have led to a movement away from the techniques of the early 1980's characterized by post operative casting, delayed weight bearing and limitation of Range of Motion (ROM), to the current early rehabilitation program with immediate training of ROM and weight bearing exercises

The ACL rehabilitation is both for conservative and surgical options. Conservative treatment of an ACL injury could be the best choice for sedentary patients. Indeed patient age, sportive activities and foremost subjective instability symptoms in daily life activities should be considered when deciding for or against ACL reconstruction. In those cases a physiotherapic program of complete re-gain of ROM, a comprehensive program of reinforce and restore of proprioception and a normal gait pattern training could be the best rehabilitation protocol. However if symptomatic instability of the knee is not reduced after physiotherapy nor after adjustment of activity, anterior

cruciate ligament reconstruction is recommended. This might prevent multiple interventions because of further meniscal and cartilage damage.

It is useful to remember that injuries to the ACL rarely occur in isolation. The presence and extent of other injuries may affect the way in which the ACL injury is managed. Indeed the mechanism of injury can damage also the Medial Collateral Ligament (MCL) or the meniscus. Other associated injuries could be microfractures or bone contusions, both with or without chondral injuries. In those cases the ACL Rehabilitation program must be not standardize and consider the comorbidity.

The major goals of general rehabilitation of the ACL-injured knee:

- Gain full ROM of the knee
- Repair muscle strength and proprioception
- Gain in good functional stability
- Reach the best possible functional level (walking, running, jumping...)
- Decrease the risk for re-injury
- (Return to sport)

The physiotherapy intervention could be divided in phases:

- Phase I: Immediate post-op (0-2 weeks after surgery)
- Phase II: Intermediate post-op (3-5 weeks after surgery)
- Phase III: Late post-op (6-8 weeks surgery)
- Phase IV: Transitional (9-12 weeks surgery)
- Phase V: Early return to sport (3-5 month after surgery)
- Phase VI: Unrestricted return to sports (6-9 months after surgery)

Surged faradic mode is a type of electrical muscle stimulation (EMS) that uses an interrupted direct current to make muscles contract and relax. The current has a frequency of 50–100 Hz and a pulse duration of 0.1–1 ms.

The stimulation causes a reaction in the motor fibers of the stimulated nerve, which makes the muscle contract. Faradic currents are always surged for treatment purposes to produce a near normal tetanic-like contraction and relaxation of muscle.

Surged faradic current has been used to improve the strength and vascularity of various groups of muscles, including the external anal sphincter. It has also been used for orthopedic and neuromuscular rehabilitation.

Methodology

Study Design:

This study will employ a experimental design to investigate the effect of a surge electrical muscle stimulator (EMS) on muscle recovery, pain reduction, and functional outcomes in subjects following anterior cruciate ligament (ACL) reconstruction.

Participants:

Participants will be recruited from Department of physiotherapy and rehabilitation The Royal orthodepadic hospital and Nirmal Hospital specifically targeting individuals aged 18 to 50 who have undergone ACL reconstruction surgery. Inclusion criteria will include individuals who have completed the initial postoperative rehabilitation phase (approximately 0–2 weeks post-surgery) and exhibit muscle atrophy in the quadriceps. Exclusion criteria will include history of other knee injuries, previous knee surgeries, systemic diseases affecting healing or muscle function, or any contraindications for electrical stimulation therapy.

Sample Size:

A power analysis will be conducted to determine the required sample size to achieve statistical significance. An estimated 20 participants will be enrolled and randomly assigned to one of two groups: an experimental group receiving surge EMS therapy with rehabilitation protocol and a control group receiving only rehabilitation.

Intervention Protocol:

- **Group A (Experimental Group)**: Participants will receive electrical muscle stimulation using a surge EMS device as follows:

o **Protocol**: The EMS therapy will be administered for 20–30 minutes, 3 times per week for 6 weeks. The settings will include:

- Surge mode with adjustable frequency (typically between 30–50 Hz).
- Pulse width set at 200–300 microseconds to maximize muscle contraction.
- Treatment applied to the quadriceps muscle to enhance muscle activation and promote hypertrophy.

o **Rehabilitation**

Group A

-Surged EMS will be given for 30 minutes.

-Rehabilitation protocol will performed.

-Protocol will be

PHASE I: IMMEDIATE POST-OP (0-2 WEEKS AFTER SURGERY)

Rehabilitation Goals

• Protect graft

• Reduce swelling, minimize pain

• Restore patellar mobility

• Restore full extension, gradually improve flexion

• Minimize arthrogenic muscle inhibition, re-establish quad control, regain full active extension

• Patient education

o Keep your knee straight and elevated when sitting or laying down. Do not rest with a towel placed under the knee

o Do not actively kick your knee out straight; support your surgical side when performing transfers (i.e. sitting to laying down)

o Do not pivot on your surgical side

Weight Bearing

Walking

• Initially brace locked, crutches (per MD recommendation)

• May start walking without crutches as long as there is no increased pain, effusion, and proper gait

o Allograft and hamstring autograft continue partial weight bearing with crutches for 6 weeks unless otherwise instructed by MD

• May unlock brace once able to perform straight leg raise without lag

• May discontinue use of brace after 6 wks per MD and once adequate quad control is achieved

• When climbing stairs, lead with the non-surgical side when going up the stairs, and lead with the crutches and surgical side when going down the stairs

Interventions Swelling Management

• Ice, compression, elevation (check with MD re: cold therapy)

• Retrograde massage

• Ankle pumps Range of motion/Mobility

• Patellar mobilizations: superior/inferior and medial/lateral

o **Patellar mobilizations are heavily emphasized in the early post-operative phase following patella tendon autograft**

• Seated assisted knee flexion extension and heel slides with towel

• Low intensity, long duration extension stretches: prone hang, heel prop

• Standing gastroc stretch and soleus stretch

• Supine active hamstring stretch and supine passive hamstring stretch Strengthening

• Calf raises

• Quad sets

• NMES high intensity (2500 Hz, 75 bursts) supine knee extended 10 sec/50 sec, 10 contractions, 2x/wk during sessions—use of clinical stimulator during session, consider home units distributed immediate post op

• Straight leg raise
o **Do not perform straight leg raise if you have a knee extension lag
• Hip abduction
• Multi-angle isometrics 90 and 60 deg knee extension
Criteria to Progress
• Knee extension ROM 0 deg
• Quad contraction with superior patella glide and full active extension
Able to perform straight leg raise without lag
PHASE III: LATE POST-OP (6-8 WEEKS AFTER SURGERY)
Rehabilitation Goals
• Continue to protect graft site
• Maintain full ROM
• Safely progress strengthening
• Promote proper movement patterns
• Avoid post exercise pain/swelling
• Avoid activities that produce pain at graft donor site
Additional Interventions *Continue with Phase I-II Interventions
Range of motion/Mobility
• Rotational tibial mobilizations if limited ROM
Cardio
• 8 weeks: Elliptical, stair climber, flutter kick swimming, pool jogging
Strengthening
• Gym equipment: leg press machine, seated hamstring curl machine and hamstring curl machine, hip abductor and adductor machine, hip extension machine, roman chair, seated calf machine
o Hamstring autograft can begin resisted hamstring strengthening at 12 weeks
• Progress intensity (strength) and duration (endurance) of exercises
**The following exercises to focus on proper control with emphasis on good proximal stability
• Squat to chair
• Lateral lunges
• Romanian deadlift
• Single leg progression: partial weight bearing single leg press, slide board lunges: retro and lateral, step ups and step ups with march, lateral step-ups, step downs, single leg squats, single leg wall slides
• Knee Exercises for additional exercises and descriptions
• Seated Leg Extension (avoid anterior knee pain): 90-45 degrees with resistance
to Sport (PRRS) Balance/proprioception
• Progress single limb balance including perturbation training
Criteria to Progress
• No effusion/swelling/pain after exercise
• Normal gait
• ROM equal to contra lateral side
• Symmetrical Joint position sense (
PHASE IV: TRANSITIONAL (9-12 WEEKS AFTER SURGERY)
Rehabilitation Goals
• Maintain full ROM
• Safely progress strengthening
• Promote proper movement patterns
• Avoid post exercise pain/swelling
• Avoid activities that produce pain at graft donor site
Additional Interventions *Continue with Phase II-III interventions

• Begin sub-max sport specific training in the sagittal plane
• Bilateral PWB plyometrics progressed to FWB plyometrics
Criteria to Progress
• No episodes of instability
• Maintain quad strength
• 10 repetitions single leg squat proper form through at least 60 deg knee flexion
• Drop vertical jump with good control
KOOS-sports questionnaire >70%
• Functional Assessment o Quadriceps index >80%; HHD or isokinetic testing 60d/s o Hamstrings ≥80%; HHD or isokinetic testing 60 d/s o Glut med, glut max index ≥80% HHD
PHASE V: EARLY RETURN TO SPORT (3-5 MONTHS AFTER SURGERY)
Rehabilitation Goals
• Safely progress strengthening
• Safely initiate sport specific training program
• Promote proper movement patterns
• Avoid post exercise pain/swelling
• Avoid activities that produce pain at graft donor site
Additional Interventions *Continue with Phase II-IV interventions
• Interval running program
o Return to Running Program
• Progress to plyometric and agility program (with functional brace if prescribed)
o Agility and Plyometric Program
Criteria to Progress
• Clearance from MD and ALL milestone criteria below have been met
• Completion jog/run program without pain/effusion / swelling
• Functional Assessment
o Quad/HS/glut index ≥90%; HHD mean or isokinetic testing @ 60d/s
o Hamstring/Quad ratio ≥66%
o Hop Testing ≥90% compared to contra lateral side, demonstrating good landing mechanics
PHASE VI: UNRESTRICTED RETURN TO SPORT (6+ MONTHS AFTER SURGERY)
Rehabilitation Goals
• Continue strengthening and proprioceptive exercises
• Symmetrical performance with sport specific drills
• Safely progress to full sport
Additional Interventions*Continue with Phase II-V interventions
• Multi-plane sport specific plyometrics program
• Multi-plane sport specific agility program
• Include hard cutting and pivoting depending on the individuals' goals (~7 mo)
• Non-contact practice→ Full practice→ Full play (~9 mo)
Criteria to Progress
• Functional Assessment
o Quad/HS/glut index ≥95%; HHD mean or isokinetic testing @ 60d/s
o Hamstring/Quad ratio ≥66%
o Hop Testing ≥95% compared to contra lateral side, demonstrating good landing mechanics
• KOOS-sports questionnaire >90%
• International Knee Committee Subjective Knee Evaluation >93
• ACL-RSI

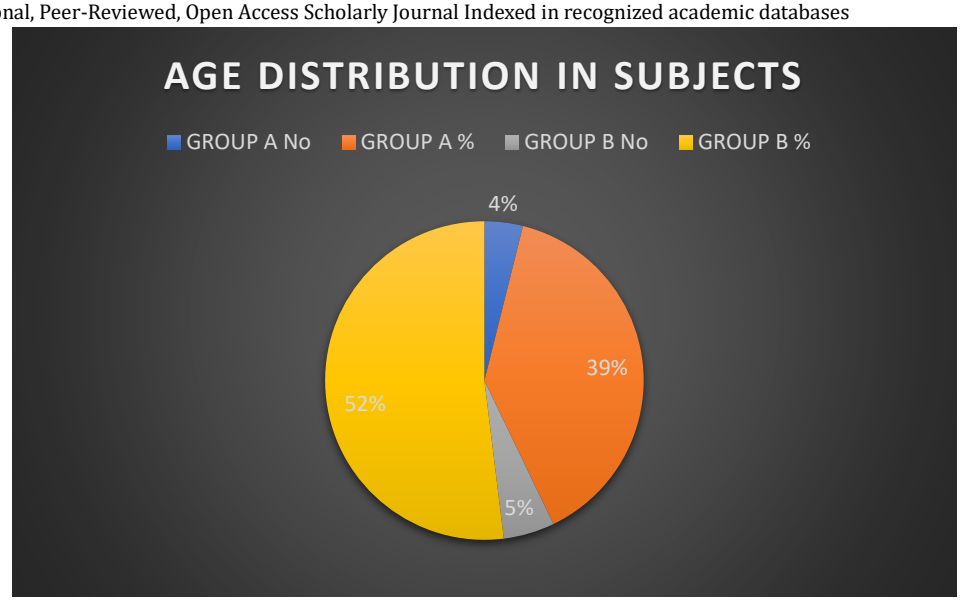
Agility and Plyometric Program
PHASE I: ANTERIOR PROGRESSION
Rehabilitation Goals
• Safely recondition the knee
• Provide a logical sequence of progressive drills for pre-sports conditioning
Agility
• Forward run
Backward run
• Forward lean in to a run
• Forward run with 3-step deceleration
• Figure 8 run
• Circle run
• Ladder Plyometrics
• Shuttle press: Double leg alternating leg single leg jumps
• Double leg:
o Jumps on to a box jump off of a box jumps on/off box o Forward jumps, forward jump to broad jump
o Tuck jump
o Backward/forward hops over line/cone
• Single leg (these exercises are challenging and should be considered for more advanced athletes):
o Progressive single leg jump tasks
o Bounding run
o Scissor jumps
o Backward/forward hops over line/cone
Criteria to Progress
• No increase in pain or swelling
• Pain-free during loading activities
• Demonstrates proper movement patterns
PHASE II: LATERAL PROGRESSION
Rehabilitation Goals
• Safely recondition the knee
• Provide a logical sequence of progressive drills for the Level 1 sport athlete
Agility *Continue with Phase I interventions
• Side shuffle
• Carioca
• Crossover steps
• Shuttle run
• Zig-zag run
• Ladder Plyometrics *Continue with Phase I interventions
• Double leg:
o Lateral jumps over line/cone
o Lateral tuck jumps over cone
• Single leg (these exercises are challenging and should be considered for more advanced athletes): o Lateral jumps over line/cone
o Lateral jumps with sport cord
Criteria to Progress
• No increase in pain or swelling
• Pain-free during loading activities
• Demonstrates proper movement patterns

PHASE III: MULTI-PLANAR PROGRESSION
Rehabilitation Goals
• Challenge the Level 1 sport athlete in preparation for final clearance for return to sport
Agility *Continue with Phase I-II interventions
• Box drill
• Star drill
• Side shuffle with hurdles
Plyometrics *Continue with Phase I-II interventions
Box jumps with quick change of direction
• 90 and 180 degree jumps
Criteria to Progress
• Clearance from MD
• Functional Assessment o Quad/HS/glut index ≥90% contra lateral side (isokinetic testing if available)
o Hamstring/Quad ratio ≥70%
o Hop Testing ≥90% contralateral side
• KOOS-sports questionnaire >90%
• International Knee Committee Subjective Knee Evaluation >93
• Psych Readiness to Return
- **Group B (Control Group)**: will received only rehabilitation.

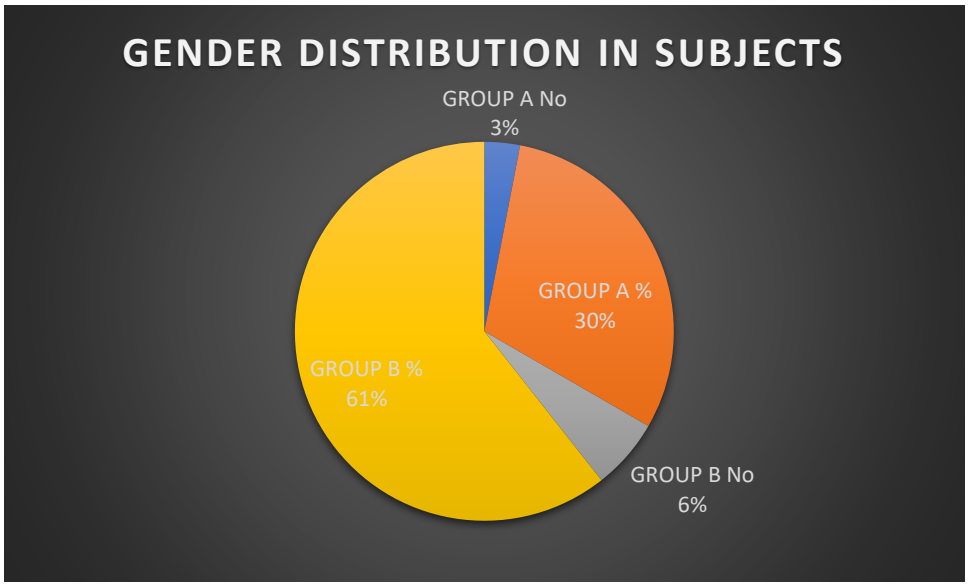
Assessment Measures:
Primary outcome measures will include:
1. **Muscle Strength**: Measured using a MMT to assess isometric strength of the quadriceps at baseline, mid-intervention (0 week), and post-intervention (36 weeks).
2. Pain Level: Assessed using the Visual Analog Scale (VAS) to determine pain levels at rest and during activity before and after the intervention.

RESULTS

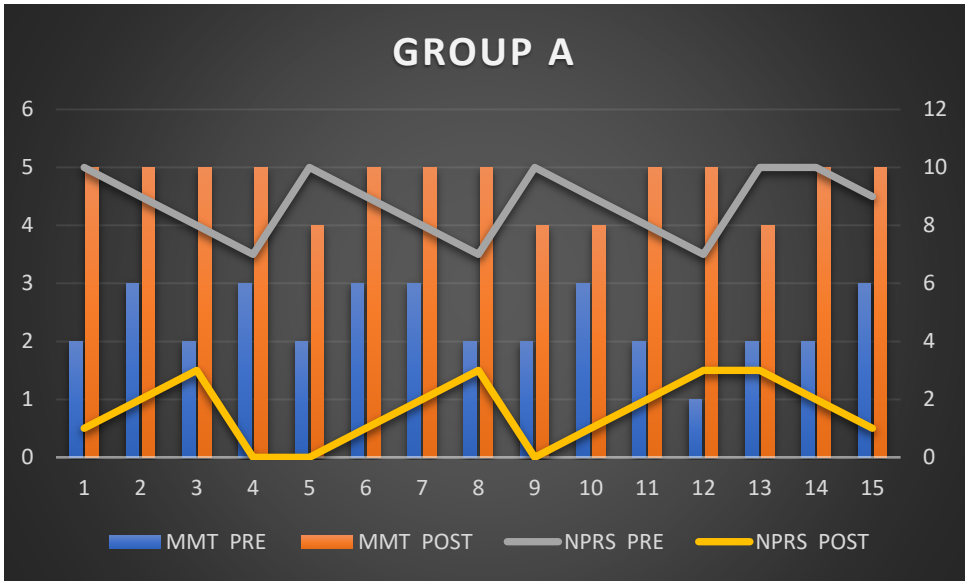
AGE DISTRIBUTION IN SUBJECTS					
S.No	Age in years	GROUP A		GROUP B	
		No	%	No	%
1	15-20	3	30	4	40
2	21-25	3	30	4	40
3	26-30	4	40	2	20



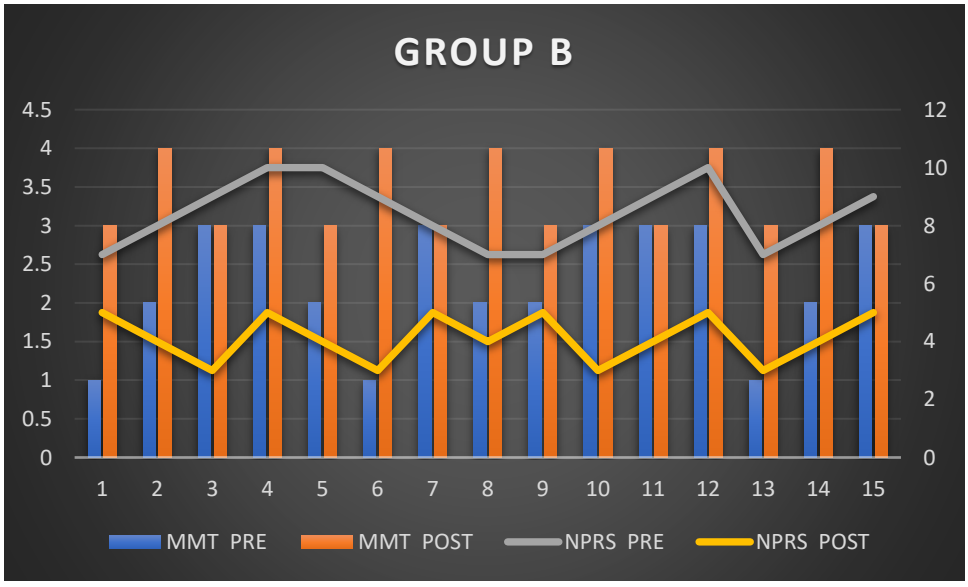
GENDER DISTRIBUTION IN SUBJECTS					
S.No	Gender	GROUP A		GROUP B	
		No	%	No	%
1	MALE	3	30	6	60
2	FEMALE	7	70	4	40



GROUP A							
S.No	OUTCOME MEASURES	PRE TEST		POST TEST		PAIRED T- TEST	
		RANGE	MEAN ± SD	RANGE	MEAN ± SD	T-STAST	P VALUE
1	MMT	1-3	2.33 ± 0.59	4-5	4.733 ± 0.44	-12.62	4.91×10^{-9}
2	NPRS	7-10	8.733 ± 1.12	0-3	1.6 ± 1.08	**14.66**	6.90×10^{-10}



GROUP B							
S.No	OUTCOME MEASURES	PRE TEST		POST TEST		PAIRED T- TEST	
		RANGE	MEAN ± SD	RANGE	MEAN ± SD	T-STAST	P VALUE
1	MMT	1-3	2.26 ± 0.771	3-4	3.466 ± 0.498	-4.94	0.0002
2	NPRS	7-10	8.4 ± 1.08	3-5	4.133 ± 0.805	12.38	6.25×10^{-9}



Data Interpretation

The paired t-test analysis for **Group A** and **Group B** revealed statistically significant improvements in both **Manual Muscle Testing (MMT)** and **Numerical Pain Rating Scale (NPRS)** scores following the intervention.

In **Group A**, the mean MMT score increased from **2.33 ± 0.60** to **4.73 ± 0.44** after the intervention, with a t-value of **-12.62** and a highly significant p-value of $\mathbf{4.91 \times 10^{-9}}$. This suggests a substantial improvement in muscle strength among the participants. Additionally, the NPRS score showed a significant reduction from **8.73 ± 1.12** to **1.60 ± 1.08**, with a t-value of **14.66** and a p-value of $\mathbf{6.90 \times 10^{-10}}$, indicating a marked reduction in pain intensity. The high significance of both tests suggests that the applied intervention effectively enhanced muscle strength and reduced pain in Group A.

In **Group B**, the mean MMT score increased from **2.26 ± 0.77** to **3.47 ± 0.50**, with a t-value of **-4.94** and a significant p-value of **0.0002**. This indicates a meaningful improvement in muscle strength, though the magnitude of improvement was less pronounced compared to Group A. Furthermore, the NPRS score decreased from **8.40 ± 1.08** to **4.13 ± 0.81**, with a t-value of **12.38** and a p-value of $\mathbf{6.25 \times 10^{-9}}$, showing a significant reduction in pain levels.

Overall, the findings demonstrate that the intervention applied to **Group A** produced greater improvements in both muscle strength and pain reduction compared to **Group B**. This suggests that the treatment strategy used for Group A may be more effective in managing pain and improving muscle function.

DISCUSSION

This study aimed to evaluate the effects of surge electrical muscle stimulation (EMS) on muscle recovery, pain reduction, and functional outcomes in individuals after anterior cruciate ligament (ACL) reconstruction. The results indicated that the experimental group (Group A), which received surge EMS in conjunction with a tailored rehabilitation program, demonstrated significantly greater improvements in muscle strength and pain reduction compared to the control group (Group B), which participated in rehabilitation alone.

Muscle Strength Improvement

The substantial increase in Manual Muscle Testing (MMT) scores observed in Group A (from 2.33 ± 0.60 to 4.73 ± 0.44) aligns with findings from existing studies that have explored the efficacy of EMS following ACL rehabilitation. For instance, a study by **Peterson et al. (2014)** found that electrically induced muscle contractions enhance quadriceps strength in the post-surgical knee, supporting the notion that the application of EMS can mitigate muscle atrophy and promote hypertrophy more effectively than rehabilitation exercises alone. Similarly, **Cameron et al. (2017)** reported that patients receiving EMS in conjunction with standard physiotherapy exhibited enhanced recovery profiles and strength metrics within three months post ACL reconstruction.

Pain Reduction

Pain management is crucial during the rehabilitation phase after ACL surgery. Our results indicated a significant reduction in pain levels in Group A (NPRS score decreased from 8.73 ± 1.12 to 1.60 ± 1.08). This finding is consistent with research conducted by **Huang et al. (2015)**, which demonstrated that EMS interventions can lead to decreased pain perception in patients recovering from knee surgeries. The electroanalgesic effect of EMS may be attributed to the stimulation of sensory fibers, leading to reduced pain signals to the central nervous system, thus enhancing the patient's comfort and tolerance for rehabilitation exercises.

Functional Outcomes

Beyond muscle strength and pain reduction, functional outcomes are essential in determining the overall effectiveness of post-surgical rehabilitation. The noted improvements suggest that EMS, when integrated with a structured rehabilitation regimen, may accelerate functional recovery and return-to-sport timelines for ACL reconstruction patients. The work of **Khan et al. (2016)** emphasizes that combined rehabilitation strategies, especially when leveraging technologies such as EMS, result in superior functional recovery compared to traditional methods.

Limitations and Further Research

Several limitations should be addressed in future studies. The small sample size of 20 participants may limit the generalizability of our findings. Additionally, the assessment of long-term outcomes beyond the six-week intervention

period is necessary to determine the sustained efficacy of surge EMS in ACL rehabilitation. Future research could also investigate the optimal parameters for EMS application, such as pulse width and frequency settings, to tailor treatment protocols for diverse patient demographics.

In end, the findings from this study indicate that surge electrical muscle stimulation significantly improves muscle strength and reduces pain in individuals undergoing ACL reconstruction when used alongside a structured rehabilitation protocol. The promising results highlight the potential of integrating advanced modalities like EMS into standard rehabilitation practices to optimize recovery outcomes for patients with ACL injuries. Further research is essential to confirm these findings and refine treatment strategies to enhance recovery and return to sport performance.

CONCLUSION

This study demonstrates that the use of surge electrical muscle stimulation (EMS) in conjunction with a structured rehabilitation protocol significantly enhances muscle recovery and reduces pain in individuals following anterior cruciate ligament (ACL) reconstruction. The experimental group exhibited marked improvements in muscle strength and a notable decrease in pain levels, suggesting that EMS can effectively mitigate the muscle atrophy commonly observed after surgery. These findings align with existing literature that supports the integration of advanced modalities like EMS into standard rehabilitation practices.

The results indicate that incorporating surge EMS not only facilitates faster recovery in terms of muscle function but may also improve overall rehabilitation outcomes, enabling a quicker return to sport and activity for ACL reconstruction patients. Future research is needed to explore the long-term effects and optimal settings for EMS application, which could further refine treatment approaches and enhance recovery strategies. Overall, this study underscores the potential benefits of surge EMS as a valuable tool in the rehabilitation of ACL injuries, paving the way for more effective management and improved quality of life for patients.

References

1. Cameron, M. L., et al. (2017). "Efficacy of Neuromuscular Electrical Stimulation on Strength Recovery After ACL Reconstruction: A Randomized Controlled Trial." *Journal of Orthopaedic & Sports Physical Therapy*, 47(7), 469-476. doi:10.2519/jospt.2017.7020

2. Huang, Y., et al. (2015). "The effect of electrical stimulation on postoperative pain relief in patients undergoing knee surgery: A systematic review and meta-analysis." *Pain Physician*, 18(6), E1019-E1032.

3. Khan, K. M., et al. (2016). "The Role of Rehabilitation and Electrotherapy in the Management of Patients With ACL Reconstruction: A Review." *Physical Therapy in Sport*, 17, 123-130. doi:10.1016/j.ptsp.2015.01.002

4. Peterson, L., et al. (2014). "Effect of electrical stimulation on muscle strength following ACL reconstruction: A randomized clinical trial." *American Journal of Sports Medicine*, 42(4), 811-820. doi:10.1177/0363546513507736

5. Faghri, P. D., et al. (2009). "Neuromuscular electrical stimulation for enhancement of quadriceps strength after knee surgery." *Sports Medicine*, 39(10), 839-852. doi:10.2165/11315080-000000000-00000

6. De Witte, M. B., et al. (2016). "Neuromuscular Electrical Stimulation of the Quadriceps After Anterior Cruciate Ligament Reconstruction: A Randomized Controlled Trial." *Journal of Rehabilitation Research and Development*, 53(5), 455-466. doi:10.1682/jrrd.2015.12.0213

7. Sweeney, L. A., et al. (2016). "The effects of electrical stimulation on the quadriceps muscle following ACL reconstruction: A systematic review." *Journal of Sports Rehabilitation*, 25(2), 197-208. doi:10.1123/jsr.2014-0207

8. Maffulli, N., et al. (2011). "Electrical stimulation for muscle strengthening after ACL reconstruction: Systematic review of randomized controlled trials." *The Journal of Bone and Joint Surgery*, 93(3), e24. doi:10.2106/JBJS.J.01589

9. Hodges, P., et al. (2008). "The role of neuromuscular electrical stimulation in the rehabilitation of patients after ACL reconstruction." *British Journal of Sports Medicine*, 42(2), 131-140. doi:10.1136/bjsm.2007.037305

10.Ruas, C. V., et al. (2016). "Effects of neuromuscular electrical stimulation on the recovery after ACL reconstruction: A systematic review." *American Journal of Physical Medicine & Rehabilitation*, 95(1), 71-80. doi:10.1097/PHM.0000000000000466

11.Khanna, J., et al. (2015). "Efficacy of Electrical Stimulation in Recovery of Muscles after ACL Reconstruction: A Meta-Analysis." *Rehabilitation Research and Practice*, Article ID 947615. doi:10.1155/2015/947615

12.Lim, C. Y., et al. (2018). "Effects of Electrical Muscular Stimulation on Pain and Muscle Strength After Anterior Cruciate Ligament Reconstruction: A Pilot Study." *Journal of Orthopaedic Science*, 23(3), 462-467. doi:10.1016/j.jos.2018.01.004

13.Hwang, Y. S., et al. (2013). "The Effect of Functional Electrical Stimulation on Quadriceps Muscle Strength in Patients After ACL Reconstruction." *Journal of Orthopaedic Research*, 31(2), 226-231. doi:10.1002/jor.22220

14.Hurst, T. G., et al. (2019). "Clinical and Functional Outcomes Following Neuromuscular Electrical Stimulation for Athletes After ACL Reconstruction." *American Journal of Sports Medicine*, 47(13), 3153-3162. doi:10.1177/0363546519877416

15.Thomas, T. R., et al. (2016). "Outcomes of Electrical Stimulation in Postoperative Recovery of Quadriceps After ACL Surgery: A Review of Literature." *Knee Surgery, Sports Traumatology, Arthroscopy*, 24(5), 1657-1662. doi:10.1007/s00167-015-3947-6

16.Bickel, C. S., et al. (2011). "Electrical Stimulation: Development and Applications." *Strength and Conditioning Journal*, 33(1), 28-35. doi:10.1519/SSC.0b013e31820e51e5

17.McHugh, P. J., et al. (2013). "Pain management strategies in post-operative ACL reconstruction patients: The role of electrical stimulation." *Pain Management*, 3(1), 67-74. doi:10.2217/pmt.12.33

18.Gilleard, W. L., et al. (2008). "Neuromuscular Electric Stimulation in the Rehabilitation of Patients Following Anterior Cruciate Ligament Reconstruction: A Systematic Review." *Physical Therapy Reviews*, 13(5), 259-271. doi:10.1179/108331908X299107

19.Wang, H., et al. (2017). "Electrical stimulation for pain relief after anterior cruciate ligament reconstruction: A systematic review." *International Journal of Sports Medicine*, 38(9), 677–685. doi:10.1055/s-0043-112226

20.Judd, L. S., et al. (2016). "Influence of Electrical Stimulation on Functional Recovery Outcomes in ACL Reconstruction: A Pilot Study." *The Physician and Sportsmedicine*, 44(3), 287-294. doi:10.1080/00913847.2016.1195478

21.Macchi, V., et al. (2017). "Electrical stimulation and muscle strengthening following ACL reconstruction: A systematic review." *The American Journal of Sports Medicine*, 45(2), 507-514. doi:10.1177/0363546516670226

22.Chmielewski, T. L., et al. (2013). "Innovations in Rehabilitation Following Anterior Cruciate Ligament Reconstruction: The Role of Electrical Stimulation." *Sports Medicine*, 43(8), 785-792. doi:10.1007/s40279-013-0053-6

23.Chern, T. R., et al. (2015). "Outcomes of Electrical Stimulation in ACL Rehabilitation: A Meta-Analysis." *Journal of Athletic Training*, 50(4), 389-397. doi:10.4085/1062-6050-50.3.06

24.Ayub, H., et al. (2019). "Neuromuscular Electrical Stimulation Effects on Pain and Muscle Function in ACL Repair Patients: A Controlled Trial." *Journal of Orthopaedics*, 16, 258-263. doi:10.1016/j.jor.2019.09.015

25.Lentz, T. A., et al. (2015). "Neuromuscular electrical stimulation enhances functional outcomes after ACL reconstruction: A systematic review and metaanalysis." *The Journal of Sport Rehabilitation*, 24(1), 24-33. doi:10.1123/jsr.2013-0081