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Impact Of Isoinertial Training On Muscle Power, Endurance, Isometric Strength, And Balance: An Experimental Trial In Post-ACL Reconstruction Patients

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Abstract

Background and Purpose: ACL reconstruction patients commonly face transient limitations in range of motion due to postoperative swelling and stiffness, along with muscle weakness and atrophy, especially in the quadriceps. A comprehensive rehabilitation program is crucial for restoring normal knee function and optimizing recovery, emphasizing exercises to address these impairments and regain strength and flexibility. The use of the flywheel resistance training has been shown to provide an increased eccentric muscle loading and improve strength. With limited research on the combined effects of isoinertial training and conventional rehabilitation, the study aims to investigate their impact on muscle power, endurance, isometric strength, and balance in postoperative ACL reconstruction patients.

Methodology: A total of 96 out of 136 screened patients aged 18-45 years, 3 weeks postop patients were included as per selection criteria and randomly divided into groups. Group A consisted of 47 patients(n=47) and administered isoinertial training protocol along with conventional rehabilitation protocol for 30 minutes whereas 49 patients in group B(n=49) recieved conventional rehabilitation protocol only for 30 minutes over 6 weeks. The patients were assessed for muscle power, endurance, isometric strength and balance using flywheel ergometer (D11 Plus; Desmotec, Biella, Italy) before and after the 6 weeks of interventions.

Results: The study demonstrated statistically significant improvements in Muscle Power (both concentric and eccentric), Isometric strength, and Balance in both Groups A and B ($p < 0.05$). Notably, while there was no significant difference in muscle endurance within Group B, the comparison between the two groups showed no statistical significance in the improvement of mean values for Muscle Power (concentric), Isometric strength, and Balance ($p > 0.05$). However, a significant improvement in mean values of muscle power (eccentric) was observed in Group A ($p < 0.05$).

Conclusion: It is concluded that the effectiveness of both 6-week protocols— isoinertial training combined with conventional rehabilitation and conventional rehabilitation only—in

enhancing muscle power (concentric and eccentric), isometric strength, and balance. The isoinertial protocol, however, showed improvement in endurance, unlike the conventional rehabilitation group. Notably, no significant difference was found in isometric strength and balance between the two intervention programs. The analysis further highlighted the effectiveness of isoinertial training in enhancing power during the eccentric phase.
, the bioremediation process is the ideal option for removing chlorpyrifos from farming soil samples. In this regard, in this present study is aimed to isolate the chlorpyrifos degradation potential of soil microbes from pesticide contaminated agricultural fields. The chlorpyrifos is identified using Gas Chromatography and Mass Spectroscopy analysis and microbial stains such as P aeruginosa and B. huaxiensis and A. niger and F. incarnatum species were identified using 16 S rRNA gene sequencing technique. Samples following a 14-day duration of incubation, the HPLC examination of the remaining chlorpyrifos showed P. aeruginosa, B. huaxiensis, A. niger, and F. incarnatum all had a higher percentage of chlorpyrifos that had been degraded than 47%, 71%, 65.3%, and 40.4%, respectively. Among these, the B. huaxiensis bacteria showed highest degradation against Chlorpyrifos and decrease in the level of pesticides in the mineral salt medium. These results demonstrate the potential for these microbes to be employed in the removal of pesticide waste that has gotten into the environment and also show that the isolate B. huaxiensis is more effective at degrading chlorpyrifos in liquid culture and can also be used in bioremediation of soils that have gotten into the environment contaminated with chlorpyrifos.

Keywords: ACL reconstruction, isoinertial training, conventional rehabilitation, muscle power

INTRODUCTION

The knee is one of the most commonly injured joints of the human body and carries an increased risk of injury with sports participation. Recent research states approximately 40% of all ligamentous knee injuries are ACL related and 70% of all ACL injuries occur during sports. [1]

Sporting activities involving jumping, cutting and decelerating are ranked the highest provokers of ACL injury, therefore injuries to the ACL are commonplace in many sports including football, basketball, skiing, netball, volleyball and rugby.[2] Injury to the ACL can lead to recurrent episodes of instability at the knee joint, increasing the risk of further injury. However, with the advancement of surgery and rehabilitation, rupture of the ACL is no longer thought to be a career threatening injury. Current study estimated that 89% of professional football players' return to their previous level of sport after knee injury.[3, 4]

Many studies have been performed over the years with respect to evaluating ACL surgery, outcomes and rehabilitation.[5] Evidences suggested that, the focus of much of the research is perturbation training and injury prevention. Perturbation training (which can involve sportspecific and dynamic proprioceptive exercises) is common in ACL rehabilitation following surgery in an attempt to lessen the likelihood of recurrence and possibly, to correct the cause for the initial injury. [6, 7]

Another suggested that rehabilitation concepts after anterior cruciate ligament (ACL) reconstruction continue to advance rapidly. A review of the recent literature reveals that the efficacy of functional knee bracing after ACL reconstruction and perturbation training programs in non-operative, pre-operative and post-operative rehabilitation programs. Also discussed is the need for criteria-based progression through the late stages (return to sports) of the ACL reconstruction rehabilitation.[8] Many study advocated that eccentric overloading training is significantly effective for rehabilitation following ACL reconstruction surgery.[9]

Isoinertial Training (IT) is "recent advanced technique which is becoming very popular in globally for rehabilitation of the patients. The isoinertial modality provides additional eccentric load. Flywheel-based isoinertial exercise was originally designed to maintain muscle health of astronauts during spaceflights.[10] It employs isoinertial technology, rather than gravity dependent weights, which allows for maximal concentric and eccentric muscle actions, with brief episodes of eccentric overload.[11]

The use of the flywheel resistance training has been shown to provide an increased eccentric muscle loading and improve strength.[12] Isoinertial exercise produces greater muscle hypertrophy and peripheral neural adaptations than weight-loaded resistance exercise in healthy subjects, probably due to the eccentric overload.[13]

Previous research studies suggested that various rehabilitation protocols have been found to be effective for the management of Anterior Cruciate Ligament reconstruction surgeries patients. It has been observed that isoinertial concentric- eccentric maximal exercise session does not cause clinically significant muscle damage and post training delayed onset muscle soreness (DOMS) and it is becoming one of the rehabilitation methods for various post-surgical rehabilitation protocols. However the treatment technique does not stand alone for the maximum benefits. Since only few case studies have been performed as combination therapy, there is dearth in literature regarding the combined effects of isoinertial training for eccentric strengthening in Anterior Cruciate Ligament reconstruction surgeries. Thus, the purpose of the study is to investigate the effect of isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only on muscle power, endurance, isometric strength and balance in postoperative patients who underwent ACL reconstruction surgery.

METHODOLOGY

The study employed an interventional experimental design within the framework of a randomized controlled trial, adhering to CONSORT (Consolidated Standards of Reporting Trials) guidelines, to assess the efficacy of isoinertial eccentric overload strengthening in conjunction with traditional rehabilitation methods in patients undergoing Anterior Cruciate Ligament (ACL) reconstruction surgeries. The research was conducted at Fortis Hospital Ludhiana, Punjab, India, spanning from July 2020 to September 2023. Ethical approval was obtained from the Institutional Human Ethical Committee, and the study was registered with the clinical trials.gov registry (CTRI/2021/09/036933). All patients provided verbal and written consent, and ethical principles outlined in the World Medical Association's Declaration of Helsinki (2013) and Good Clinical Practice (Indian Medical Research Council) were strictly followed.

The sample size of 95 patients, considering a 15% dropout rate, was determined using G Power software, based on statistical power (80%), effect size (0.25), and alpha (0.05). Patients were randomly divided into two groups, Group A and Group B, using a lottery method. Group A received isoinertial strengthening in combination with conventional rehabilitation protocol, while Group B underwent conventional rehabilitation protocol only. Inclusion criteria encompassed patients aged 18-45, three weeks post ACL reconstruction surgery, with the procedure conducted by the same surgeon using a Semi-tendinosis gracilis graft. Exclusion criteria consisted of patients with previous ACL reconstruction surgery, a history of previous knee surgery, unwillingness to sign the consent form, pre-existing physical limitations affecting gait or lower limb activity, inability to perform isoinertial training, and a lack of understanding of English, Hindi, or Punjabi language.

The study involved screening 130 ACL reconstruction surgery patients at Fortis Hospital, with 96 meeting the selection criteria. All the patients were assessed for muscle power, endurance, isometric strength, and balance using flywheel ergometer (D11 Plus; Desmotec, Biella, Italy). The interventions lasted for six weeks for 60 minutes in group A and 30 minutes in group B respectively, and assessments were conducted at baseline and after the intervention period.

Flywheel ergometer (D11 Plus; Desmotec, Biella, Italy): The lower extremity isometric strength test (ISOMET) was performed with peak force measured on an isoinertial device (D11 full, Desmotec, Biella, Italy). The participant was connected to the device by a strap with one end tied to the device

and the other to a waistcoat worn by the participant. The strap was tightened not to allow the respondent to move up. The Desmotec device has two contact panels that are connected to a computer equipped with the software (D.Soft, Desmotec, Biella, Italy). The participant stands in a semi-squat position, flexion at 100 degrees angle, and his hands are placed on his hips. At the sign, the subject exerts pressure on the plates for 10 s, maximum voluntary isometric contraction. The contact panels measure the force that the participant produces and which is read on the computer. Thus, muscle power eccentric and concentric along with isometric strength and endurance was assessed. For the assessment of balance, the patient stands on the platform with loaded plates for 10 sec in a semi-squat position, flexion at 100 degrees angle, and his hands are placed on his hips, any deviation from the zero either on left or right side was observed and percentage of deviation was thus monitored.[14]

INTERVENTIONS

Group A: Forty seven subjects were included in experimental group in which additional isoinertial strengthening protocol was given twice a week for six weeks 30 minutes in combination with conventional (Table1) which was administered daily for six weeks till phase 2 and half as this is a ongoing for 30 minutes for six days per week.[15]

In this protocol, maximum power peak, muscle endurance, balance shift, total work done & maximal isometric force was measured on flywheel ergometer (D11 Plus; Desmotec, Biella, Italy). Eccentric overload training was performed by a half squat exercise using a fly-wheel ergometer (D11 Plus; Desmotec, Biella, Italy). The protocol included squatting and lunges on pressureplate platform of fly-wheel ergometer, 3 sets of 10 repetitions each, performed twice weekly[49], interspersed by 1 minutes of passive recovery. Each repetition was evaluated qualitatively by an investigator, offering kinematic feedback to the subjects and strong standardized encouragements to perform maximally into target power zone. The patients were instructed to perform the concentric phase with maximal velocity and to control the eccentric phase until knee achieves approximately 90° of flexion. The following combined load will be used for each patient during EOL exercise: 1 large disc (diameter 0.285m; mass 1.9 kg; inertia 0.02 $kg \cdot m^2$) and 1 medium disk (diameter 0.240m; mass 1.1 kg; inertia 0.008 $kg \cdot m^2$).The inertia of the ergometer (D11 Plus) is estimated at 0.0011 $kg \cdot m^2$.[16]

Table 1: Description of Conventional rehabilitation protocol

Phases(Weeks)	Criteria for progression	Details of the Protocol
Phase 1 (Week 1)	-	• Control of pain and inflammation (i.e., through cryotherapy and exercises). • Obtain ROM of 0-90*, emphasizing achievement of full extension (i.e., through CPM and exercises: patellar mobilization in all directions, heel slides and leg elevation with a pillow under the heel). • Regain muscle control, with safe isometric and isotonic OC (ROM 90*-40*) and CC (ROM 0*-60*) strength exercises without additional weight. (i.e., SLR, mini squads, shifting body weight). • Improve gait pattern. If pain is tolerated, aim at walking without crutches from day 4. Sufficient neuromuscular control and a non-limping gait pattern are criteria for walking without crutches
Phase 2 (Week 2 to Week 9)	• Pain knee is equal to previous week or less (VAS-score pain). • Minimal swelling (measurement with measuring tape).	• Apply cryotherapy in case of pain or swelling (if necessary after each therapy session). • Work toward full ROM (maintain full extension, 120* flexion from week 2 and 130* flexion

	• Full extension and 90 flexion are possible (ROM goniometer). • Good patellar mobility compared with contralateral side. • Sufficient quadriceps control to perform a mini squad 0-30 and SLR in multiple directions. • Ability to walk independently with or without crutches	from week 5) with remaining attention for good patellar mobility. • Walking without crutches from day 4 to 10. Normalize gait pattern with walking exercises (treadmill from week 3 and jogging in a straight line from week 8). • Isometric and isotonic strength training increasing in intensity (quadriceps, hamstring, gastrocnemius and soleus), with increasing ROM for OC and CC exercises without extra weight. For OC exercises: weeks 2, 3 and 4 from 90* to 40*, afterward 10* toward extension to be added every week. For CC exercises: weeks 2-7 from 0* to 60* and from week 8 from 0* to 90*. • Start neuromuscular training by slowly increasing from static stability to dynamic stability. Work toward confidence on the vestibular and somatosensory system for balance, with increasing surface instability and decreasing visual input. • Start from week 3 with cycling on an ergometer and swimming. • Start from week 4 with stepping on a stair-stepping machine. • Start from week 8 with outdoor cycling. Caution: act adequately in case of persisting pain, inflammation or limited ROM. There is a risk of developing arthrofibrosis (in case of doubt consult the orthopedic surgeon).
Phase 3 (Week 9 to Week 16)	• Minimal pain and swelling (VAS-score pain, measurement of knee swelling with measuring tape). • Full extension and at least 130* flexion possible (ROM goniometer). • Normal gait pattern. • Exercises of previous week are carried out properly. • Administer the IKDC questionnaire.	• Obtaining and maintaining full ROM. • Optimizing muscle strength and endurance. Add increasing weights from week 9 both for OC and CC exercises. • Neuromuscular training with increasing emphasis on dynamic stability and plyometric exercises, slowly increasing duration and speed. Start with two-legged jumping and work slowly toward one-legged jumping. Normalize running with outdoor jogging from week 13.
Phase 4 (Week 16 to Week 22)	• No pain or swelling in the knee (VAS-score pain, measuring knee swelling with measuring tape). • Full flexion and extension of the knee (ROM goniometer). • Administer the IKDC questionnaire again. • Quadriceps and hamstring strength >75% compared to the contralateral side. Difference in hamstring/quadriceps strength ratio is <15% compared to the contralateral side (optional isokinetic strength testing of knee flexors and extensors at 180 per second). • Hop tests >75% compared to the contralateral side. • Exercises of previous week are carried out properly.	• Maximizing muscle endurance and strength. • Maximizing neuromuscular control with emphasis on jumping, agility training and sport- specific tasks. Variations in running, turning and cutting maneuvers are allowed. Duration and speed to be increased and maximized.
-	Criteria for returning to sports • No pain or swelling (VAS-score pain, measuring knee swelling with measurement tape). • Full flexion and extension of the knee is possible (ROM-Goniometer). • Quadriceps and hamstring strength >85%	Exercises of previous week are carried out properly, and the patient tolerates sport-specific activities and agility training with maximal duration and speed

	compared to the contralateral side. Difference in hamstring/quadriceps strength ratio is <15% compared to the contralateral side (optional isokinetic strength testing of knee flexors and extensors at 60*, 180*and 300*per second and an endurance test at 180* per second). • Hop tests >85% compared to the contralateral side. • Exercises of previous week are carried out properly, and the patient tolerates sport-specific activities and agility training with maximal duration and speed. • Administer the IKDC questionnaire again.	

Group B: In group B, a total of 49 patients were administered conventional rehabilitation Protocol for the total of 6 weeks for 30 minutes daily for six days per week till week 6 of phase2 and half as this is a ongoing study. The details of the interventional program is given in Table 1 [15].

STATISTICAL ANALYSIS

Data analysis was done by SPSS software. Baseline characteristics were compared between groups using independent t- test. For all the outcome measures, Student's t test was used to assess the interventions effects within the groups. Alpha was set at 0.05, and the 95% confidence interval (CI) was calculated. If the significant difference was detected, then independent t test was conducted.

RESULTS

The mean age (years) of patients included in this study in group A was 29.94±6.78 and in group B was 30.20±7.45. The demographic profile of the patients namely age, height, weight as well as baseline values of muscle power, endurance, isometric strength and balance were matched and found to be having statistically non-significant difference.

Table 2 describes the comparison of mean values of Muscle Power, Endurance, Isometric strength and Balance before and after the intervention within the two groups in post operated patients with ACL reconstruction surgery. The analysis of the results showed that there is statistical improvement in the values of Muscle Power (both concentric and eccentric), Isometric strength and Balance in both the groups A and B ($p < 0.05$). Whereas, as far as muscle endurance is concerned, no statistical significant difference was found in the group B at two different intervals (0 week and 6th week) at $p > 0.05$.

Further, the analysis regarding improvement of mean values of Muscle Power (concentric), Isometric strength and Balance revealed that there is no statistical significant difference found between the two groups, A and B ($p > 0.05$). However, the statistical significant difference was observed in the improvement of mean value of muscle power (eccentric) in group A at $p < 0.05$.

Table 2: Comparison of mean values of Muscle Power, Endurance, Isometric strength and Balance before and after the intervention within the two groups

Parameters	Group A(Exp)				Group B			
	Week 0 Mean±S.D	Week 6 Mean±S.D	t value	P value	Week 0 Mean±S.D	Week 6 Mean±S.D	t value	P value
Muscle Power	79.00±19.35	173.53±49.91	16.420	<0.0001(S)*	80.61±25.78	172.51±50.32	18.109	<0.0001(S)*

Concentric(W)								
Muscle Power Eccentric(W)	68.19±15.37	178.40±41.96	25.880	<0.0001(S)*	89.20±18.57	163.10±36.11	24.780	<0.0001(S)*
Endurance(sec)	10.98±3.28	14.85±3.87	9.499	<0.0001(S)*	11.10±2.39	11.65±2.26	1.826	0.0740(NS)
Isometric strength(kg)	166.70±33.15	216.33±36.60	7.210	<0.0001(S)*	161.30±41.08	211.93±42.71	22.630	<0.0001(S)*
Balance(%)	6.54±2.71	3.23±2.10	7.313	<0.0001(S)*	7.16±2.08	4.00±2.50	7.210	<0.0001(S)*

NS- Non Significant
S- Significant

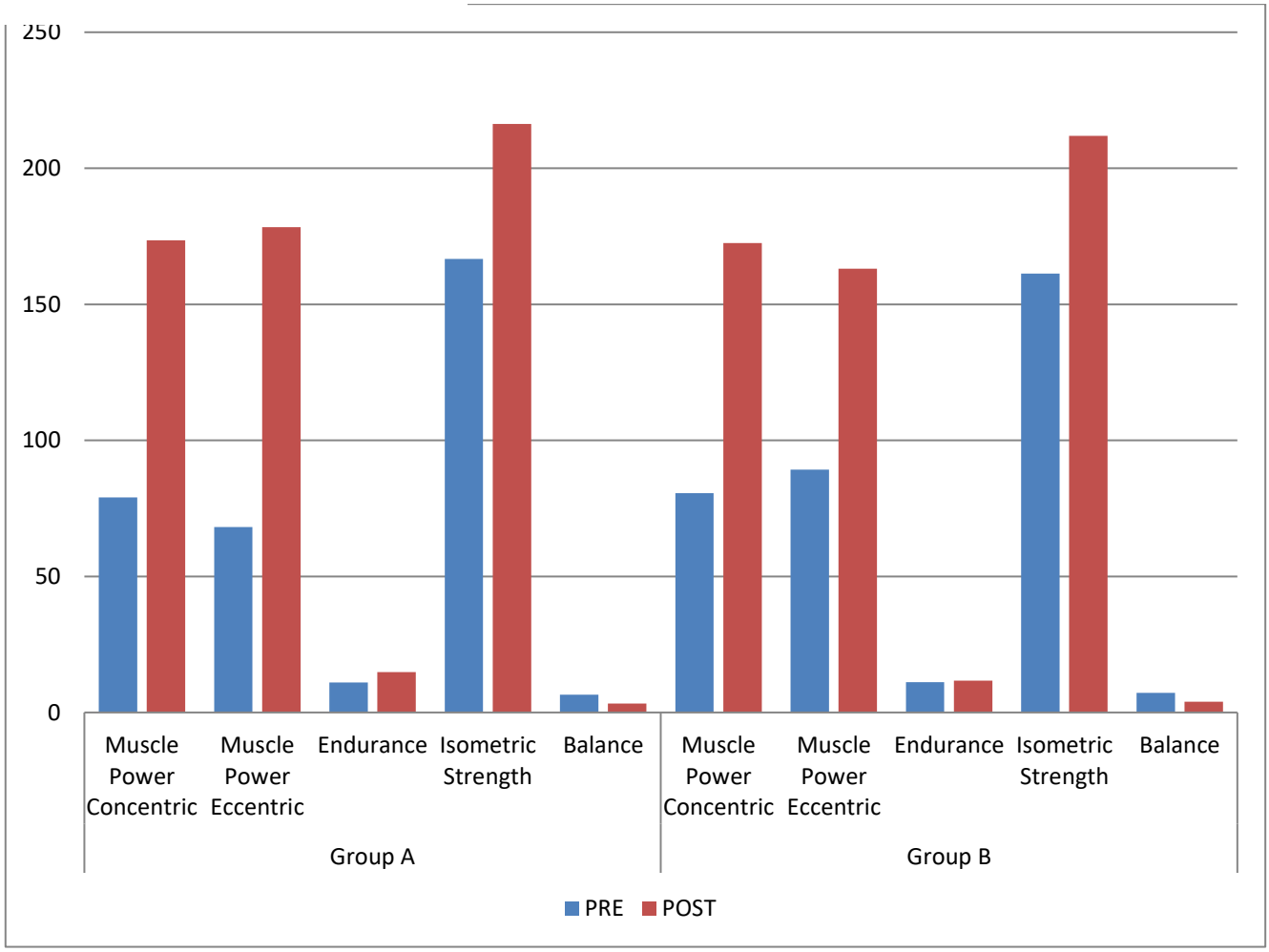

Figure 1: Graphical representation of comparison of mean values of Muscle Power, Endurance, Isometric strength and Balance

Table 3: Comparison of improvement in the mean values of Muscle Power, Isometric strength and Balance

Parameters at 0 week vs 6 week	Group A(Exp) Mean±S.D	Group B Mean±S.D	t value	P value
Muscle Power Concentric(W)	94.53±39.47	91.90±35.52	0.344	0.731(NS)
Muscle Power Eccentric(W)	110.21±29.19	73.90±20.8	7.032	<0.001(S)*
Isometric strength(kg)	49.63±19.88	50.62±15.66	0.271	0.786(NS)
Balance(%)	-3.311±3.10	-3.16±3.07	0.233	0.815(NS)

NS- Non Significant
S- Significant

The present study investigated the effect of isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only on muscle power, endurance, isometric strength and balance in postoperative patients with ACL reconstruction surgery over 6 weeks. This study showed that both the groups in which patients received interventions isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only respectively improved muscle power both in concentric and eccentric phases, isometric strength and balance whereas isoinertial training protocol along with conventional rehabilitation protocol improve endurance but in contrast, the current study did not found improvement in the group B in which patients were administered conventional rehabilitation protocol only.

Muscle power encompassing both concentric and eccentric components is crucial for rehabilitation in post operated ACL reconstruction patients. Concentric muscle contraction, involving muscle shortening, essential for regaining joint stability and functional strength. Eccentric contractions, characterized by muscle lengthening, play a vital role in controlled movement during activities like descending stairs, enhancing muscle flexibility, and promoting tendon healing. In the present study, both the groups A and B showed improvement in the muscle power both in eccentric and concentric phases. The study's findings are in accordance with the study done by Alli Gokeler (2014) and Daniel Lorenz (2014).[17,18]

Further analysis of improvement in the mean power in eccentric phase showed that isoinertial training protocol along with conventional rehabilitation protocol is more effective than conventional rehabilitation protocol only. In the study conducted by M de Hoyo (2014) greater eccentric load is a peculiarities of flywheel exercises, since during the positive (extension) phase of a squat, the subject executes a high velocity movement (generally maximal) while during the negative (flexion) phase of the squat, the subject has to break the load accumulated during the previous phase.[19] Therefore, the principal advantage of EOL is related to an enchained mechanical load. Previous studies done by authors supposed that a high eccentric load may have better stimulated higher order motor units (which require the utilization of high load), which may have guaranteed a positive transfer in motor unit recruitment, force, and power production.[16,20]

Muscle endurance is important for enhancing overall functional capacity, allowing patients to engage in daily activities with reduced fatigue and also contributes to the restoration of normal gait patterns and joint stability. According to the current findings of this study, the patients showed improvement in muscle endurance, receiving isoinertial training protocol along with conventional rehabilitation protocol from 10.98 to 14.85 whereas no improvement was observed in patients administered with conventional rehabilitation protocol only. As there is scarcity of published literature, the improvement in group A could be due to the fact that Eccentric muscle action results in higher

maximal torque than concentric muscle action.[21] Neural activation is, however, not larger with eccentric muscle action as indicated by maximal electromyographic (EMG) activity, which may be lower than in concentric actions. However, by producing greater muscle tension, eccentric muscle actions may enhance protein synthesis in muscles and contractile tissues. The soreness after eccentric exercise will lessen over the first week of continuous training.[22] As eccentric muscle action is part of many natural movement patterns, especially when the stretch-shortening cycle is used, muscle endurance is improved.

Isometric strength and balance are integral components of the postoperative rehabilitation for ACL (Anterior Cruciate Ligament) reconstruction patients. Isometric strength, involving static muscle contractions without joint movement, is particularly valuable in rebuilding strength around the knee joint, enhancing stability and minimizing muscle atrophy without subjecting the joint to excessive stress. Isometric strength also contribute to neuromuscular control, a crucial element in regaining coordination and preventing compensatory movements. Concurrently, balance play a vital role in improving proprioception and joint awareness, essential for reducing the risk of falls and re-injuries. This finding of the present study showed that both the groups in which patients received interventions isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only improved isometric strength and balance. Further analysis of improvement in the isometric strength and balance showed that neither of the two interventional programs i.e. isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only is more effective than the other. As, very few studies have compared such interventions on isometric strength and balance in postoperative ACL reconstruction (ACLR) patients; therefore, conducting an exhaustive comparison with the literature is challenging. The improvement in the group A was observed as Isoinertial exercises, involving flywheel training, provide a variable resistance throughout the range of motion, challenging muscles eccentrically and concentrically. This dynamic loading not only improves isometric strength but also targets muscles in a way that closely mimics functional movements. Consequently, this group may demonstrate greater gains in both isometric strength and balance due to the more comprehensive nature of their strength training. Also, as the conventional rehabilitation protocol included isometric exercises, which are effective in stabilizing the knee joint and building static strength. Patients in this group experience enhanced neuromuscular control, contributing to improved balance. This could be the possible explanation for the improvement observed in the above mentioned parameters.

This study has few limitations that are acknowledged. Due to the nature of the intervention, it was not feasible to blind therapists to group allocation. A direct comparison between the isoinertial training protocol and conventional training protocol was not conducted. Additionally, a long-term follow-up was not carried out, limiting the assessment of sustained effects over an extended period. Despite these constraints, this study supported the efficacy of isoinertial eccentric-oriented training along with conventional rehabilitation protocol. The future scope of the study involves conducting long-term follow-up assessments, 4-5 months post-rehabilitation, to investigate the sustained impact on activity levels and lifestyle changes. This extended observation period would provide valuable insights into the enduring effects of the rehabilitation protocols and their influence on the patients' daily activities and overall lifestyle.

CONCLUSION

The study concluded the effectiveness of both the protocols for 6 weeks that is, isoinertial training protocol along with conventional rehabilitation protocol and conventional rehabilitation protocol only in improving muscle power both in concentric and eccentric phases, isometric strength and balance whereas isoinertial training protocol along with conventional rehabilitation protocol improve endurance but in contrast, the current study did not found improvement in the group B in which patients were administered conventional rehabilitation protocol only. Further analysis revealed that isoinertial training protocol along with conventional rehabilitation protocol is effective in improving power in eccentric phase. However, as far as isometric strength and balance is concerned, neither of the two interventional programs proved more superior than the other.

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