(ISSN: 0973-7049(P))

The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(1): S.I (1), 1343-1361, 2026 www.thebioscan.com

Comparative Effectiveness of Static Versus Dynamic Balance Training on Clinical Recovery Outcomes Following Anterior Cruciate Ligament Reconstruction: An Experimental Study

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DOI:https://doi.org/10.63001/tbs.2026.v21.i01.S.I(1).pp1343-1361

KEYWORDS
ACL Recontruction,
Static Balance training,
Dynamic Balance training ,
Neuromuscular Rehabilitation,
Postural Stability,
Propriception,
Functional Performance ,
Numeric Pain Scale

Article Info
Received: 28.02.2026
Accepted: 17.03.2026
Published: 27.03.2026

Abstract

Backgroung and Objective – Anterior Cruciate ligament (ACL) reconstruction is most prevalent surgical procedure in Sport medicine and post operative rehabilitation targeting Neuromuscular recovery which widely recorgnised as essential component to get optimal functional outcomes.Balance training includes both static and dynamic exercise is an essential component of post ACL reconstruction rehab.However evidence direct compare the differential effect of static vs dynamic balance training programme on clinical recovery outcomes which is insufficient.This study was intended to address the gap by comparing experimentally both approaches across three primary clinical outcomes domains which is Balance performance ,pain intensity and functional performance ,in patient following ACL reconstruction

Methods : An experimental ,two group ,Pre- test and Post – test comparative study was conducted at Department of Physiotherapy ,Pacific Medical College anf hospital ,Udaipur. 30 post ACL reconstruction patient (age between 20-40 yr; <4 months post – operative) were equally and randomly divided into Group A (Static balance Training,n = 15) and Group B (Dynamic Balance Training ,n = 15).All participants received their respective intervention 6 days per week for four weeks in which each session last for 45-60 minutes.Primary outcomes measure the Balance board Score (1-100),Numeric Pain Scale (NPS,0-10) and Functional Performance Score (0 -100) Assessed before and after intervention.Statistiacl analysis applied using Paired t – test for within –group comparison and Indepenent t- test for between –group comparison, with significance set at $p< 0.05$

Result: Both Intervention groups demonstrated statistically significant improvements ($p<0.001$) in all three primary clinical outcomes.Group A (Static) achieved a post intervention means of Score 73.73 ± 8.28,NPS 3.22 ± 0.85, and Functional Performnace 77.86 ± 8.17: Group B (Dynamic) achieved higher score than Group A which is Balance Score 76.27 ± 6.99,NPS 2.54 ± 0.46,and Functional Performance 83.7 ± 4.55. comparison between group confirmed that Group B significantly performed well than Group A in all three measure ($p< 0.005$) with smaller standard deviations across all dynamic training outcomes reflect greater consistency of neuromuscular adaptation.

Conclusion: Both static and Dynamic balance training are effective post- ACL reconstruction rehabilitation produce product significant clinical improvement.Dynamic balance training is statistically higher across all primary clinical measure and should be prioritized in the intermediate and advanced phases of post – operative rehab.A staged progression from static to dynamic training is recommended as the evidence-based standard of care.

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1. INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is a surgical procedure which is performed to repair a torn ACL which is one of the primary stabilizing ligament of knee joint. Rupture of this ligament is commonly associated with sudden deceleration ,pivoting ,jumping and cutting movements which is characteristic of high – demand sports .The ligament connect the tibia to the femur and plays crucial role in maintaining knee joint stability during dynamic physical activity. Distortion of ACL impairs complex sensorimotor mechanism which responsible for dynamic joint stability resulting in long-term functional deficits that persist after acute injury phase and continue to affect patients even after surgical repair.[1]

ACL injuries is one of the most prevalent musculoskeletal injuries in advance sports medicine , affecting approximately 200,000 to 300,000 individual annually in the United State, with significantly higher global incidence figures [2].This condition primary affect young physically active individual and competitive athletes in sports demanding rapid directional changes ,including football,basketball,handball ,volleyball and rugby. Female athletes have 2 to 8 times higher chance of getting ACL injury risk compared to males, the variation is largely due to anatomical, hormonal and neuromuscular factors including narrow intercondylar notch dimension,greater quadriceps angle , hormonal ligament laxity influences, and neuromuscular activation asymmetries during dynamic tasks [3].In the Indian context ,the incidence of ACL injuries has increased significantly over the past two decades ,driven by increase participation in sports and improved diagnostic accessibility,establishing it as an increasingly important condition in physiotherapy and orthopedic practice.

Surgical ACL reconstruction is the widely considered treatment of choice for physically active individuals seeking return to sports or occupationally demanding activity. Surgical procedure involve replacing the torn ACL with biological or synthetic graft – most commonly used graft is hamstring tendon autograft using the doubled semitendinosus and gracilis tendons to form a four –strand construct – secured within femoral and tibial tunnels at the anatomical footprints of the native ligaments [4].However, surgery alone does not ensure complete functional recovery. After surgical repair the graft undergone the process of ligamentisation – it involves biological remodeling ,revascularization and reinnervation – over a period of 12 to 24 months. During this periods comprehensive multi- phased physiotherapy intervention play important role restoring neuromuscular control, joint proprioception, muscular strength, and sports –specific performance readiness.[4,5]

A key clinical consequence of ACL injury is the damage to the mechanoreceptors in the ligaments which is responsible for providing continuous afferent sensory input – involves joint position sense, velocity of angular displacement and load magnitude – to the central nervous system . This damage result in proprioception deficits manifest as impaired postural stability, delayed protective mmuscle reaction time , altered movement strategies and reduced capacity for dynamic joint stabilization – collectively increase the risk of of functional instability and re – injury [11]. Recovering of these propriception and neurophysiologiacal challenge of post ACL reconstruction management.

Balance training involve both static and dynamic postural control,has emerged as the primary therapeutic approaches that restore proprioception function and neuromuscular coordination after ACL reconstruction. Static exercise include maintaining postural stability in a fixed position without active movement –

(ISSN: 0973-7049(P))

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which progress from bilateral stance to unilateral stance and stable to unstable surfaces – which provide targeted proprioception and neuromuscular stimulation while involving comparatively low mechanical demand ideal for early phase of recovery [19].On the other side Dynamic balance exercise involve maintaining postural control while the body is actively engaged in motion – through weight shifting, stepping, hopping, and uniquely enagaing feed forward neuromuscular control mechanism that protect the reconstructed ACL during functional loading[23]

Despite widespread clinical application of both exercise, the available comaparative evidence about their differential effects on clinical recovery outcomes is limited and methologicalaccuracy.Very few studies have conducted systematic head to head comparison of separate static and dynamic balance training in controlled experimental designs and the majority of existing studies has included limited outcomes parameters[28].This study is therefore intended to address this evidence gap by conducting a systematic experimental comparison of both training exercise across three primary clinical outcomes – balance performance ,pain intensity , and functional performance - in a controlled post ACL reconstruction population providing clinically reliable comparative evidence based rehabilitation prescription[29].

1.1 AIM AND OBJECTIVES

The primary aims of this study was to analyse and compare the effects of static and dynamic balance training on clinical recovery outcomes in patients after ACL reconstruction. Specific objective were (i) to assesss and compare pre and post intervention balance score using the Balance board in both groups; (ii) to evaluate pre and post –intervention pain level using the Numeric Pain Scale in both groups (iii) to assess and compare changes in functional performance score following Static and Dynamic balance training (iv) to determine which balance training gives superior clinical intervention outcomes in post ACL reconstruction patients.

1.2 RESEARCH HYPOTHESES.

Null Hypothesis (H_0) : There is no significant difference in functional recovery outcomes between static and dyammic balance training in individual after ACL reconstruction.

Alternative Hypothesis (H_1) : There is a significant difference in functional recovery outcomes between Static and Dynamic balance training in individual after ACL reconstruction.

2. REVIEW OF LITERATURE

Relph, Herrington ,and Tyson (2014) conducted a systemic review confirming consistent deficits in joint position sense, threshold to detection of passive motion, and force reproduction accuracy in ACL injured subjects with deficits persisting for month to years following both injury and reconstruction, highlight the necessity of sustained rehabilitation targeting neuromuscular control.The mechanoreceptors of the ligaments are severely affected following ACL injury which responsible for providing afferent sensory input to the central nervous system about joint position,velocity and load [11].

Palmieri-Smith, Thomas and Wojtys (2008) demontrastrated neuromuscular function after ACL injury and reconstruction,evaluated changes in quadriceps and hamstrings activation which includes reduced co-contraction ratios and altered muscle activation timing during dynamic tasks.These neuromuscular changes were linked to increase anterior tibial shear forces,aberrant

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joint loading, increase re injury risk - establishing the theoretical foundation for neuromuscular and balance training as necessary rehabilitation component [8]

Solomonow and Krogsgaard(2001) Demonstrated the existence of ligamentomuscularreflex- which mechano receptor in the ACL trigger reflex hamstering activation in response to anterior tibial translation - providing a critical line of dynamic joint defence which is damage after ACL injury necessitates compensatory strategies through enhance neuromuscular control and optimised postural responses.

Hewett, Stroupe and Nance (1996) established the scientific basis for neuromuscular training as both and injury prevention and post injury rehabilitation strategy and demonstrate effectiveness in reducing Valgus knee collapse and improve hamstring to quadriceps strength ratios.

Risberg, Mork and Jenssen (2001) conducted a systemic review of randomised control trial comparing neuromuscular training which includes static balance exercise with convention strength training after ACL reconstruction, it showed that the neuromuscular training group gained superior improvement in joint position sense, functional knee stability, and return to sports at 6 month post operatively.

Hebert,Maltais and Lepage (2015) similarly Demonstrated that static balance training along with single leg stance on stable and unstable surface produced significantly improvement in sway amplitude and velocity, reports a reduction in medial- lateral and anterior- posterior centre of pressure displacement, which support improved sensorimotor integration and postural control efficiency.

Paterno.Schmitt,and Ford (2010) conducted a cohort study which demonstrate that deficits in static partial control, measured by single leg stance stability indices, persisted for up to 6 months in post ACL reconstruction athletes who had complete standard rehabilitation - these deficits strongly associated with increased re- injury risk at two years – highlight specifically targeting static postural control through dedicating training program

Grindem,Snyder- Mackler and Moksnes(2016) conducted a study that athletes meeting functional criteria including symmetrical performance or dynamic balance measures had significantly decrease re-injury rates, directly supporting the inclusion of dynamic balance assessment and training in return to sports decision making.

Myer,Paterno and Ford(2006) Demonstrated that dynamic neuromuscular training include perturbation task, reactive agility drills, plyometric exercises and sports specific movement produced significantly improvement in limb symmetry indices, dynamic Valgus angles, and self reported knee function, confirming that the clinical value of dynamic training in post ACL rehabilitation.

Gokeler,Bisschno, and Myer (2013) conducted a comparative study of balance exercise in ACL reconstructed patient, in which both static and dynamic exercises improved postural stability, dynamic exercises exerted a greater impact on functional performance metrics - particularly in those involving rapid directional changes and single leg landing task - producing more ecologically valid improvement in function performance

Kang,Oh, and Kwon (2012) concluded that the progressive protocol combining both exercises produced higher result compared to either exercise in isolation, advocating for static exercises as a foundation before systematic transition to dynamic task - a progressive subsequently supported by Augustsson and colleagues (2006).

Lephart,Pincivero and Giraldo (1997) differentiate between feedforward neuromuscular control through pre programmed motor strategies and feedback control through reactive adjustments in which dynamic balance training uniquely restore feedforward mechanism that cannot be adequately challenged bystatic task alone - particularly the rapid pre programmed muscular responses which is essential for protecting the reconstructed ACL during the initial phase of landing or cutting, a time frame which is too brief for feedback mediated correction. This theoretical differentiation provides a mechanistic framework for the clinical superiority of dynamic training observe in multiple experimental studies.

Paterno,Rahu and Schmitt (2012) documented a study in which re-injury incidence of approximately 29.5% within 2 years of return to sports after ACL reconstruction with persistent deficit in personal control and neuromuscular function identify us significant indicator of second ACL injury –establishing the critical importance of comprehensive neuromuscular rehabilitation before return to sports clearance.

Notes and Barber- Westin (2017) conducted a study that confirm in a comprehensive review that neuromuscular and balance training was among the most evidence supported component of post reconstruction rehabilitation, with programmes , including progressive static and dynamic balance challenges consistently showed higher function outcomes and lower chances of re-injury compared to convention and strength only protocols.

3. MATERIALS AND METHODS

3.1 Study Design

This study involved and experiment, two groups, pre-test and post-test comparative design. Participant were randomly allocated into two intervention groups and all outcomes measures were assessed two times : baseline which is before intervention (Pre-intervention) and after intervention period (post – intervention). The study was conducted at the Department of Physiotherapy, Pacific Medical College and Hospital,BhilokaBedia, Udaipur, Rajasthan, India, following approval from institutional Ethics committee of Pacific Medical University

3.2 Participants

A total of 30 patients who have undergoes ACL reconstruction surgery were recruited from out patient department and impatient department of the Department of physiotherapy, Pacific Medical College and Hospital, through referrals from orthopedic surgeon and physiotherapists, participant carefully assessed against predefined eligibility criteria and randomized into two groups of 15 using simple random allocation

Table 3.1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
ACL reconstruction surgery within preceding 4 month	Uncontrolled medical condition (cardiac disease, uncontrolled hypertension, diabetes mellitus)
Independence ambulation with completeaur near full range of motion with minimal pain	Age below 20 years or above 40 years
Age between 20 and 40 years	History of recent surgery other than ACL reconstruction
Confirmed post-ACL reconstruction diagnosis	Diagnose with neurological condition or cognitive impairment

3.3 Intervention Protocols

Both groups were treated to their respective interventions six days a week for four weeks. Every treatment procedure took around 45-60 minutes and had to be administered under the direct supervision of a qualified physiotherapist. Individualised exercise prescription was based on baseline baropodmetic test and balance board test with systematic re-evaluation after every third day to evaluate the progress and increase exercise challenge.

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the treatment sessions were completed within a period of 45- 60 minutes and were supervised by a trained Physiotherapist. The individualised exercise prescription was based on baseline baropadometric examination and balance board examination, and systematic re-evaluation was conducted every third day, which is covered by the miss monitor progress.

GROUP A — STATIC BALANCE TRAINING

Group A subjects were given a progressive programme of stationary balance training, which aims at enhancing postural stability and proprioceptive awareness during stationary positions. The exercise program entailed: (i) Feet-together standing with an eye-open to eye-closed gradual increasing the base of support; (ii) Semi-tandem position where one foot is slightly in front of the other with progressively decreasing base of support; (iii) Full tandem as the heel to toe stance; and (iv) Single-leg stance on the affected limb with a gradually increasing unsteady progression of the base of support (foam and balance board). All exercises were done 20-30 seconds a repetition with 3-5 repetitions a set. The progression of difficulty was facilitated by the results of serial baropodmetric and balance board re-assessment.

GROUP B -DYNAMIC BALANCE TRAINING.

The Group B subjects were also given progressive dynamic balance training programme that focused on functional movement-based exercises. The exercises were the following: front/back and lateral weight shifting, hip abduction and extension in standing, marching on the spot, calf raising, squat, leg curl, side-stepping, step-forward; single-leg squat variations. The exercises were done with a total of 10 -15 repetitions in 2-3 sets. The progression was founded on reassessment data and improvement to a combination of slow to fast movements, bilateral position to unilateral and stable surface to unstable.

3.4 OUTCOME MEASURES

Balance Performance: The evaluation was conducted with a Balance Board device. The participants were placed in a standardised stance and their ability to maintain equilibrium were rated off a 0-100 scale with the higher the rating the greater the postural stability and the neuromuscular coordination.

Pain Intensity: Measured on the Numeric Pain Scale (NPS, 0 - 10) during functional activities of walking, stair climbing, squatting and weight-bearing activities. The low scores denote less pain.

Functional Performance: The assessment is done using a standardised activity-based test, which measures the capacity of the patient to walk, climb stairs, squat, and bear weights. Measured on a scale of 0- 100 with a higher scores depicting a higher degree of functional independence.

3.5 STATISTICAL ANALYSIS.

Statistical Analysis Software (SAS) was used to do the analysis of all the data. The Shapiro-Wilk test was used to test the normality of distribution. Descriptive statistics represented the mean as standard deviation (SD). Paired t-tests were used to compare the within-group (prevs.post-intervention) comparisons. Independent samples tests t-tests were employed in order to measure the differences between groups (Group A vs. Group B after the intervention). They used a two- tailed level of significance of p = 0.05.

4. RESULTS

4.1 Demographic Characteristics

There are total of 30 participants completed the study with no dropout. There was a similarity in the demographic profile of the two intervention groups at the baseline hence homogeneity and good internal validity of the experimental design.

Table 4.1: Baseline Demographic Characteristics

Variable	Group A — Static (n = 15)	Group B — Dynamic (n = 15)
Age (years), Mean ± SD	28.1 ± 2.44	28.73 ± 2.86
Post-operative Duration (months)	2.74 ± 0.26	2.64 ± 0.26
Sex (Male/Female)	9M / 6F	10M / 5F

In Group A mean age was 28.1 ± 2.44 years in Group A and 28.73 ± 2.86 years in Group B and there were no significant inter-group differences in age. Similar results were obtained in establishing parallels in recovery stages at case of enrolment as the mean post-operative duration in Group A and Group B were same at 2.74 ± 0.26 months and 2.64 ± 0.26 months respectively. The fact that the two demographic variables are closely similar is something that makes sure that the difference in the observed post-intervention outcomes difference can be primarily attributed to the respective training protocols as opposed to the characteristics of the participants.

4.2 Within-Group Analysis — Group A (Static Balance Training)

The group A had statistically significant changes on all of three primary clinical outcome measures after the four weeks of static balance training intervention, p -value less than 0.001 on all variables.

Table 4.2: Clinical Outcomes — Group A (Static Balance Training)

Variable	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Diff	t-value	p-value
Balance Board Score (0–100)	43.06 ± 4.90	73.73 ± 8.28	+30.67	-12.33	< 0.001
Numeric Pain Scale (0–10)	6.43 ± 0.34	3.22 ± 0.85	-3.21	13.43	< 0.001
Functional Performance (0–100)	48.93 ± 2.28	77.86 ± 8.17	+28.93	-13.20	< 0.001

The balance score improved markedly from 43.06 ± 4.90 to 73.73 ± 8.28, a mean increase of 30.67 points, reflecting substantial enhancement in postural stability and proprioceptive control. Pain intensity as measured by the NPS reduced from 6.43 ± 0.34 to 3.22 ± 0.85, a clinically meaningful reduction of 3.21 points. Functional performance improved substantially from 48.93 ± 2.28 to 77.86 ± 8.17, reflecting better physical capability, joint stability, and activity tolerance. These improvements confirm that static balance training produces significant neuromuscular recovery, pain reduction, and functional gains in post-ACL reconstruction patients.

4.3 Within-Group Analysis — Group B (Dynamic Balance Training)

Group B had statistically significant and clinically significant positive changes in all three primary clinical outcome measures after the dynamic balance training intervention with all p-values less than 0.001 and difference in change was larger than that in Group A in all measures.

Table 4.3: Clinical Outcomes — Group B (Dynamic Balance Training)

Variable	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Diff	t-value	p-value
Balance Board Score (0–100)	42.40 ± 5.48	76.27 ± 6.99	+33.87	-14.75	< 0.001
Numeric Pain Scale (0–10)	6.26 ± 0.40	2.54 ± 0.46	-3.72	23.52	< 0.001
Functional Performance (0–100)	48.93 ± 2.60	83.07 ± 4.55	+34.14	-25.18	< 0.001

The balance score increased from 42.40 ± 5.48 to 76.27 ± 6.99, surpassing the improvement achieved in Group A. Pain intensity reduced substantially from 6.26 ± 0.40 to 2.54 ± 0.46 — a mean reduction of 3.72 NPS points — with a notably narrow post-intervention SD of 0.46 indicating exceptional consistency of pain relief across participants. Functional performance improved from 48.93 ± 2.60 to 83.07 ± 4.55, the highest post-intervention functional score recorded in the study. The consistently smaller standard deviations across all Group B variables compared to Group A confirm more uniform and consistent neuromuscular adaptation following dynamic training.

4.4 Between-Group Comparison

Between-group comparison of post-intervention values confirmed that Group B (Dynamic) consistently and significantly outperformed Group A (Static) across all three primary clinical outcome measures.

Table 4.4: Between-Group Comparison of Post-Intervention Clinical Outcomes

Variable	Group A Post-Test Mean ± SD	Group B Post-Test Mean ± SD	Significance
Balance Board Score	73.73 ± 8.28	76.27 ± 6.99	$p < 0.05$
Numeric Pain Scale	3.22 ± 0.85	2.54 ± 0.46	$p < 0.05$
Functional Performance	77.86 ± 8.17	83.07 ± 4.55	$p < 0.05$

Group B achieved a higher post-intervention balance score (76.27 ± 6.99 vs. 73.73 ± 8.28), lower pain score (2.54 ± 0.46 vs. 3.22 ± 0.85), and higher functional performance score (83.07 ± 4.55 vs. 77.86 ± 8.17) compared to Group A, with all differences reaching statistical significance. The substantially narrower standard deviations in Group B across all three outcome measures further confirm the superior consistency and reproducibility of clinical improvement achieved through dynamic balance training.

4.5 Overall Summary (All 30 Subjects)

Table 4.5: Overall Pre- and Post-Intervention Clinical Outcomes (N = 30)

Variable	Pre Mean ±	Post Mean ±	Mean Diff	p-value	Result

	SD	SD			
Balance Score	42.73 ± 4.3	75.2 ± 6.5	+31.47	< 0.001	Sig.
Pain (NPS)	6.34 ± 0.5	2.88 ± 0.7	-3.46	< 0.001	Sig.
Functional Performance	48.93 ± 2.2	80.46 ± 8.0	+31.53	< 0.001	Sig.

5. DISCUSSION

The present experimental study compared the effects of static and dynamic balance training on clinical recovery outcomes in patients following ACL reconstruction at the Department of Physiotherapy, Pacific Medical College and Hospital, Udaipur. The findings reveal clinically important distinctions in the magnitude and consistency of improvement achieved through each modality, while confirming the therapeutic value of both approaches.

5.1 Demographic Homogeneity and Internal Validity

Demographic homogeneity in the two interventional groups was also remarkable where both groups had a close match of means in age age of 28.1 ± 2.44 and 28.73 ± 2.86 years along with almost similar duration of post-operative months at 2.74 ± 0.26 and 2.64 ± 0.26 months respectively. Such comparability is consisitent with the established epidemiological profile of ACL injuries, which influence out of proportion to young physically active adults in their third decade of life [25]. The strong inter-group homogeneity, ensure that any observed differences after interventions are due to difference in the impact of the two training regimens, but no longer to the pre-existing individual features of the study participants, which implies high internal validity.

5.2 Effectiveness of Static Balance Training

Group A showed statistically significant results on all three main clinical outcome scales ($p < 0.001$ across all) to confirm that statical balance training is also an effective exercise of rehabilitation in post-ACL group. The increase in balance score of 43.06 ± 4.90 to 73.73 ± 8.28 consistent with the results of Risberg et al. (2001) that were able to show in a randomised controlled trial that neuromuscular training that included a balance (static) component demonstrated better joint position sense and functional knee stability as compared to standard strength-based rehabilitation. The large decrease in NPS of 6.43 ± 0.34 to 3.22 ± 0.85 is in agreement with the established mechanophysiological correlation between proprioceptive rehabilitation and modulator of pain-proprioceptive feedback- spinal gate control mechanisms work [20,21]. This functional improvement of 48.93 ± 2.28 to 77.86 ± 8.17 performs the same role as documented by Paterno et al. (2010) who showed that the targeting of the specific postural control in particular is vital in the attainment of full functional recovery although the attainment of full functional recovery of a patient occurs only up to six months post-surgery despite the fact that the patient has passed the conventional return-to-sport requirements.

5.3 Superiority of Dynamic Balance Training

Group B showed statistically significant and clinically better improvements in all clinical outcomes measure dimension with a magnitude of improvement on average increasing greater than Group A. The balance score gain of 76.27 +6.99 compared to Group A (73.73 +8.28) increases, as also indicated by Gokeler et al. (2013) who established that dynamic balance exercises led to greater increase of movement functional metrics which can be attributed to higher activation of the feedforward neuromuscular control processes during dynamic movement exercises. The 2.54 ± 0.46 level -mean of 3.72 NPS -reduced the pain and was better than Group A and corresponded to the findings of Myer et al. (2006), who showed that dynamic neuromuscular training decreased the pain and biomechanical risk factors by improving integrated feedforward and feedback neuromuscular co-contraction patterns that protect the reconstructed knee on functional loading.

The functional performance improvement to 83.07 ± 4.55 — the highest post-intervention functional score in the study — corroborates the results of Ageberg, Link and Roos (2010) seen in a randomised controlled trial that neuromuscular training with tasks involving dynamic balance resulted in significantly improved hop test results and muscle strength result at one year post-operatively supports the above results. The better pain relief with dynamic training is of special interest whether mechanistically or not: with dynamic exercises the activation of the entire lower limb kinetic chain is more extensive and more extensive integration of proprioceptive stimulation of multiple joint receptors is observed simultaneously than with relatively

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focal activation of proprioceptive processes in static exercise. Similar findings were found by Zebis, Andersen, and Ellingsgaard (2013) who determined that dynamic neuromuscular training did significantly benefit pre-landing muscle activity patterns and minimize the loading of the knee valgus during landing as well as played a key role in the better functional outcomes occurring in dynamic training groups.

5.4 Complementary Role of Both Modalities

It should be noted that the results indicated statistically significant and clinically meaningful outcomes between the baseline and both groups in all outcome measures, which is a verification of the therapeutic nature of the use of the static balance training as a modality of rehabilitation. This is in line with Augustsson et al. (2006) who showed that a gradual transition starting with balance tasks such as being able to stand on one leg then progressing to more dynamic exercises obtained higher functional performance as well as prompt recovery to sport than either of the two by themselves. The same was reported by Kang et al. (2012) who found that combined progressive systems obtain the best outcome as opposed to using each separately when they suggested the use of both modalities in a progressive rehabilitation environment.

The mechanistic explanation of why such complementarity is neurophysiologically logical provided by the theoretical framework furthered by Lephart, Pincivero, and Giraldo (1997) is that static exercises are better than dynamic exercises at restoring foundational proprioceptive stability the position-sense and sway-correction feedback mechanism which is a part of safe weight bearing functioning, and that dynamic exercises is better than a stationary postural task at occupying feedforward pre-programmed motor strategies. Both modalities should not thus be considered unnecessary in an all round rehabilitation plan but instead the evidence shouts a progressive approach of the usage of both the static to the dynamic exercises as the best rehabilitation approach.

5.5 Limitations

Reviewing the findings presents the study with a number of limitations that must be taken into consideration when interpreting the study. The sample size of 30 relatively small subjects is a limitation to the statistical power and generalisability of the findings to the wider groups of post-ACL reconstruction. The lack of control group without any form of physiotherapy, but with balance training

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protocols, precludes the direct comparison with conventional care. The two to four weeks intervention period is insufficient to reflect the duration-sustainability of the realized benefits or to predict the recovery pattern of later stages of rehabilitation. Allocation was randomised, but allocation concealment and assessor blinding were not described, which is a methodological weakness. Pain and functional performance outcome measures were based on self-report scales that were prone to subjectivity or bias in recollection.

6. CONCLUSION

This experimental study shows that three main conclusions are supported. To start with, both dynamic and static balance training programme achieves statistically significant and clinically meaningful changes, of balance performance, pain intensity, and functional performance, in patients following ACL reconstruction making both modalities evidence-based elements in the post-operative rehabilitation. Second, dynamic balance training demonstrates better clinical effectiveness based on all three primary outcomes, including balance score, pain intensity, and functional performance, with the between-group differences becoming statistically significant ($p < 0.05$), which is why the alternative hypothesis can be accepted and dynamic training during the intermediate and later scenes of rehabilitation needs a priority. Third, the standard deviations of all measures of Group B outcomes are significantly smaller consistently, which sets the dynamic training slightly more homogeneous and reproducible clinical changes of more reliable and consistent neuromuscular adaptation

It has been suggested that a gradual, phased rehabilitation process, including initially, static balance training to establish basic proprioceptive stability during the initial stages of the post-ACL reconstruction rehabilitation and then gradual transition to dynamic balance exercises to maximize neuromuscular control and functional performance is the evidence-based standard of practice of the rehabilitation of post-ACL reconstruction. The major modality of balance training during the intermediate and advanced rehabilitation stages should be dynamic balance training with a valuable preparatory base being the static training. Further studies on the neuromuscular mechanisms behind the difference in effects of the two training modalities are recommended in future studies by researchers with larger and more diverse sample population, randomised controlled study involving active control groups, longitudinal follow-up of the rate of return-to-sport and re-injury, and more sophisticated biomechanical outcome measures such as three-dimensional motion analyses and electromyography.

7. CLINICAL IMPLICATIONS

The research results of the current article have significant implication to clinical physiotherapy activities in the field of post-ACL reconstruction rehabilitation. The indicated high level of superiority of dynamic balance training to all primary indicators of clinical outcomes gives evidence-based reasons to suggest structured, progressive dynamic training as an important part of ACL rehabilitation protocols especially during intermediate and advanced post-operative periods when the necessary base strength and static postural stability have already been achieved.

To ensure the proprioceptive base needed to support safe dynamic loading, clinicians must develop rehabilitation modalities that have a gradual progressive move, where early post-operative weeks involve stable surface, followed by unstable surface balance exercises, to help one build up to the proprioceptive base. At the point of basic statical postural control demonstration, a systematic introduction of dynamic exercises beginning with periodic examination and accelerating to a functional challenge and disturbance of perturbation must be conducted in sequence with serial objective assessment results. Objective, quantitative information obtained by the use of balance board and baropodmetric assessment tools guides individualised progression decisions, prevents progression to premature levels of development that might damage the healing graft, and maximises the timing and intensity of training progressions.

The immense pain-relieve obtained by both interventions - and especially by dynamic training - is the argument that structured balance rehabilitation may be considered not merely with the aim of delivering the neuromuscular advantages to the patient but as an active pain intervention approach during the post-operative phase. Pain reduction with proprioceptive rehabilitation can enhance compliance of the patient to the rehabilitation programme generally and the faster attainment of functional milestones with secondary implications to return-to-sport schedules. It is proposed that a multidisciplinary team of physiotherapists, orthopaedic surgeons, and sports medicine experts are coordinated by an in-depth patient education on the rationale of rehabilitation and risk factors of re-injury in order to maximize patient recovery outcomes.

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