Single-Leg Dynamic Balance Training to Improve Stability on Post ACL Reconstruction

Anand Babu Kaliyaperumal[1], Babu Subbiah[2], Paulraj Manickavelu[3], Dharani Neelamegam[4], Simulia Dhinju[5]

[1]*PhD Scholar, National Institute of Technology, Puducherry, Karaikal, India*
[2]*Sports director, National Institute of Technology Puducherry, Karaikal India.*
[3]*Professor, Sri Venkateshwaraa College of Physiotherapy, Affild to Pondicherry University, Puducherry, India*
[4]*Post- Graduates, Sri Venkateshwaraa College of Physiotherapy, Affild to Pondicherry University, Puducherry, India*
[5]*Associate Professor, Jijamata College of Physiotherapy, Maharashtra, India.*
Corresponding Author: Anand Babu Kaliyaperumal, mail ID: babumpt@gmail.com,

KEYWORDS

Dynamic Balance, Plyometrics, Rehabilitation, Endurance, Hamstring Strength.

ABSTRACT

ACL injuries are a prevalent concern, particularly in athletic populations, leading to significant research efforts aimed at effective treatment and prevention. Previous studies indicate that while surgical reconstruction is common, a considerable percentage of patients do not regain pre-injury sports performance. This highlights the necessity for enhanced rehabilitation strategies focusing on dynamic balance and neuromuscular control. The study involved 90 participants were divided into three groups: a control group receiving conventional ACL rehabilitation. Conventional Rehabilitation, involving muscle strength and endurance exercises, such as stationary biking, straight leg raises, step-ups, hamstring curls, toe raises, partial squats, and wall squats. Single-Leg Dynamic Balance Training, implemented in two stages over six weeks, incorporating modified Romberg exercises, retro walking, balance board exercises, plyometric exercises, and isometric as well as isotonic strengthening exercises for the quadriceps, hamstrings, and hip muscles. The experimental group showed significant improvements in both joint position sense and SEBT scores compared to the control group. Statistical analysis revealed that the joint position sense increased significantly from 25.4 ± 4.91 to 14.93 ± 5.22 (t = 6.653833) in the experimental group, whereas the control group exhibited minimal changes. Similarly, SEBT scores improved significantly in the experimental group from 77.46 ± 5.81 to 70.4 ± 2.29 (t = 6.33956), highlighting the effectiveness of the dynamic balance training. Single-leg dynamic balance training significantly enhances knee stability post-ACL reconstruction. These findings underscore the potential benefits of incorporating targeted balance training into ACL rehabilitation programs to improve patient outcomes and reduce the risk of re-injury.

1. Introduction

The prevalence of anterior cruciate ligament (ACL) injury has been on the rise, with the incidence ranging from 2. 49 per 100,000 population in 2000-2001 to 5. 65 per 100,000 in 2014-2015, indicating a 5.6% annual increase [1].[2] ACL injuries most commonly occur due to non-contact mechanisms, such as sudden changes in direction or sudden deceleration.[3] It is estimated that there will be more than 100,000 anterior cruciate ligament tears in the Indian population over the current year.[4]

The dynamic stability of the knee joint is maintained by both passive (ligamentous) and active (neuromuscular) restraints, with the anterior cruciate ligament (ACL) serving as the primary passive restraint to anterior tibial translation.[4] The ACL also contributes to rotational stability in the frontal and transverse planes due to its specific orientation.[4]The term "stability" refers to the ability of the ACL to resist abnormal tibiofemoral translations, which could result in the sensation of the knee joint "giving way."[3][5]

The anterior cruciate ligament has been the subject of extensive biomechanical and anatomical studies, making it one of the most frequently studied structures of the human musculoskeletal system over the past decades.[6] These functions are vital for the overall stability and functionality of the knee, rendering the ACL an essential component for both everyday activities and athletic performance.

The high prevalence of ACL injuries, particularly in athletic populations, has led to a growing body of research aimed at understanding the underlying factors and developing effective prevention and treatment strategies.[7][6][8]. Surgical reconstruction is a widely adopted intervention to restore knee function and facilitate return to sports participation[2]. However, previous studies have reported that a significant portion of individuals, ranging from 8% to 50%, are unable to return to their pre-injury sports even after successful ACL reconstruction [3]. This highlights the need for targeted rehabilitation approaches to improve outcomes for these patients.

One potential approach to address this issue is through targeted rehabilitation programs that focus on improving dynamic balance and neuromuscular control. The review by Sugimoto et al. found that a multi-faceted exercise program, including balance/coordination, strength, plyometric, and agility exercises, can effectively reduce the risk of lower extremity injuries, including ACL injuries [1].

Single-leg dynamic balance training has been proposed as a specific intervention to address the unique stability challenges faced by individuals after ACL reconstruction. This type of training focuses on improving the individual's ability to maintain balance and control their movements on a single leg, which is crucial for activities and sports that involve rapid changes in direction and sudden stops [4]. Studies have shown that single-leg dynamic balance training can enhance off-axis neuromuscular control, which is essential for preventing future injuries. Furthermore, research has demonstrated the benefits of balance training for individuals with functional ankle instability, suggesting the potential for similar improvements in individuals recovering from ACL injuries[5]. By targeting specific deficits in balance and neuromuscular control, single-leg dynamic balance training may be an effective rehabilitation approach to enhance stability and reduce the risk of re-injury in patients following ACL reconstruction.

Given the promising evidence for the effectiveness of single-leg dynamic balance training in improving stability and reducing the risk of re-injury, it is crucial to further investigate its impact on ACL reconstruction outcomes.

2. Methodology

The research adopted a quantitative approach with a pre-test and post-test experimental group design to compare the effects of weight-bearing and non-weight-bearing exercises on knee stability.The study involved 90 participants with unilateral ACL-deficient knees, selected through random sampling. The study spanned 12 sessions over four weeks, with three sessions per week. It assumed that dynamic stability training could improve the stability of the affected limb. The independent variables were non-operative ACL rehabilitation and single limb dynamic stability exercise training, while the dependent variables included JOINT POSITION SENSE AND SEBT

The population consisted of individuals with unilateral ACL-deficient knees from the Physiotherapy Department at SVMCH&RC and Sri Venkateshwaraa College of Physiotherapy in Puducherry. Non-probability purposive sampling was employed to select participants based on inclusion and exclusion criteria. Inclusion criteria included availability during data collection, age 18-35, understanding Tamil or English, and unilateral ACL injury. Exclusion criteria included unwillingness to participate, recent injury, associated ligamentous injuries, knee deformities, inability to perform single-leg hopping without pain, and certain chronic conditions. The study was conducted in hospital settings with adequate facilities. A pilot study with 10% of the estimated subjects was performed to ensure research objectives were met. Ethical considerations included obtaining permission from the ethical committee and institutional authorities, informed consent from subjects, and ensuring participants' safety. Participants were screened based on inclusion and exclusion criteria, informed about the study, and gave written consent. They were randomized into three groups: Group A (control group) receiving conventional ACL rehabilitation, and Groups B and C (experimental groups) receiving conventional ACL rehabilitation and single limb dynamic stability exercise training for the knee joint.

TEST PROCEDURE:

DYNAMIC BALANCE TEST:

The Star Excursion Balance Test (SEBT) is a functional performance test used in rehabilitation and sports medicine to assess dynamic balance, lower limb strength, proprioception, and neuromuscular control. It is frequently utilized to evaluate individuals with lower extremity injuries, such as ankle sprains or knee ligament injuries, and to monitor rehabilitation progress. The test involves creating a grid or star pattern on the floor with eight lines extending outward from a central point at 45-degree intervals, marked with tape or other visible markers, each line approximately 110% of the subject's leg length. The participant, after having the test explained and demonstrated, stands on one leg in the center of the grid with arms crossed over the chest or placed on the hips, and removes their shoes.

During the test, the participant reaches as far as possible with the non-standing leg along each line, tapping the floor lightly with the toes before returning to the starting position. They are encouraged to reach as far as comfortably possible without losing balance or touching down with the non-standing foot, repeating the process for each of the eight lines, always starting and ending with the same leg. The distances reached along each line are measured and recorded using a measuring tape or ruler, ensuring a consistent measurement technique from the center of the grid to the point of toe contact. The average reach distance for each direction is calculated by averaging the distances reached on three trials for that direction, and these distances are normalized by dividing each average distance by the participant's leg length. Composite scores can be obtained by summing the normalized reach distances for all directions or specific groupings of directions.

The SEBT provides valuable information about dynamic balance, lower limb strength, and neuromuscular control. Larger reach distances indicate better balance and neuromuscular control in that direction, while asymmetries between the injured and uninjured limbs or deviations from normative data may indicate deficits or limitations. Typically, normalized reach distances range from approximately 85% to 100% of leg length, but this can vary based on factors such as age, sex, and activity level. Overall, the SEBT is a valuable tool for assessing dynamic balance and lower limb function, particularly for individuals recovering from lower extremity injuries or those seeking to improve balance and stability.

JOINT POSITION SENSE

Joint position sense was measured using a Universal Goniometer. In recent years, an increasing number of authors have recommended non-weight bearing (NWB) tests of joint position sense, as weight-bearing tests are more functional and involve all of the cutaneous, articular, and muscular proprioceptors that act in concert during normal everyday activities. The procedure for the NWB assessment was conducted in a bedside sitting position with the legs out of the plinth and the thigh fully supported. The subject was blindfolded to avoid any visual cues. The examiner passively flexed the knee joint from an extended position to the target angle of 30 degrees at a very slow speed (about 10 degrees per second). The subject attempted to identify the test position while holding it actively for 4 seconds and was then passively returned to the starting position. Five practice repetitions were given, and the subject was then asked to reproduce the target position actively using the same limb. The mean of each set of three relative errors was calculated.

TREATMENT PROCEDURE: CONVENTIONAL TREATMENT

CONVENTIONAL EXERCISES/NON-OPERATIVE REHABILITATION PROTOCOL

Patients receive 10 training sessions at a frequency of 2-3 sessions per week, depending on individual scheduling constraints. Return to part-time competitive sports or work activity is allowed in the last week of training (sessions 8-10). Patients return to full activity upon completion of the training program.

Muscle Strength & Endurance Exercises:

Stationary Bicycle: Twice a day for 10-20 minutes to help increase muscular strength, endurance, and maintain the range of motion.

Quadriceps:

1. Begin straight leg raises (SLR) with the knee immobilizer on. Perform 3 sets of 10 repetitions, 3 times a day. Start by doing these exercises while lying down. This exercise is performed by first performing a quadriceps

contraction with the leg in full extension. The leg is then kept straight and lifted to about 45-60 degrees and held for a count of six. The leg is then slowly lowered back onto the bed. Relax the muscles.

2. Step-ups: 6-8" step forward/lateral (maintain a vertical trunk, watch for hip hiking or excessive ankle dorsiflexion).
3. Eccentric lateral step down on a 2, 4, or 6" step with control (watch for hip hiking or excessive ankle dorsiflexion).
4. Static Lunge (¼ - ½ range): Progress to dynamic lunge step (¼ - ½ range) with proper trunk and leg alignment.
5. Full wall squats to 90°.

[*Note: Perform each exercise 3 sets of 10 repetitions, 3 times a day*].

Hamstrings/Gluteals:

• Prone active hamstring curls – progress with 1-2 lb weights.

• Standing hamstrings curls – when able to attain 90° ROM against gravity add 1-2 lb weights.

[*Note: Each exercises 3 sets of 10 repetitions 3 times a day].

Cavles

• Toe Raises - Using a table for stabilization, gently raise the heel off the floor and balance on the ball of the feet.

• Hold for 6 seconds and ease slowly back down.

[*Note: 3 sets of 10 repetitions each day].

Muscular control exercises:

Partial Squats:

• Place feet at shoulder width in a slightly externally rotated position.

• Use a table for stability, and gently lower the buttocks backward and downward.

• Hold for 6 seconds and repeat.

[*Note: Do 3 sets of 10 repetitions each day].

SINGLE LEG DYNAMIC BALANCE TRAINING:

SINGLE-LEG DYNAMIC BALANCE TRAINING	
Stage 1 (3 weeks)	1. Modified Romberg exercise (standing in balance with eyes closed) a. On hard ground b. On soft ground 2. Retro walking (25 m) 3. Walking on heels (25 m)

SINGLE-LEG DYNAMIC BALANCE TRAINING	
	4. Walking on toes (25 m) 5. Walking with eyes closed (25 m) 6. Standing on one extremity for 30 s (repeated in both extremities) ▪ Leaning forwards, backwards, and sideways on one extremity (eyes open) ▪ Leaning forwards, backwards, and sideways on one extremity (eyes closed) ▪ Sitting down and standing up from a high chair slowly
Stage 2 (3 weeks)	**Stage 1 exercises plus the following:** 1. Exercise with a balance board 2. Sitting down and standing up from a low chair slowly 3. Plyometric exercise (crossing a height of 15 cm by jumping) 4. a. Walking slowly, wide circle (D:120 cm) b. Walking quickly, wide circle (D:120 cm) c. Walking slowly, narrow circle (D:45 cm) d. Walking quickly, narrow circle (D:45 cm)
Strengthening exercise program (3 times per week for 6 weeks)	
Stage 1 (2 weeks)	1. 5-min fixed bike exercise without resistance 2. ROM exercise 3. Quadriceps muscle isometric strengthening exercise 4. Hamstring muscle isometric strengthening exercise
	Isometric exercises: 8 repetitions of 6-s maximum isometric voluntary contraction with 2-s rest
Stage 2 (2 weeks)	**Stage 1 exercises plus the following:** 1. Short-arc terminal extension exercise with weight for the knee joint 2. Isometric exercise for the adductor muscles of the hip joint 3. Isometric exercise for the abductor muscles of the hip joint
	Isotonic exercises: short arc extension of the knee with a step

SINGLE-LEG DYNAMIC BALANCE TRAINING	
	placed as support. Applied as 10 repetitions with one third weight of the 10-RM, 10 repetitions with two thirds weight of the 10 RM, and 10 repetitions with the full weight of the 10-RM
Stage 3 (2 weeks)	**Stage 1 and 2 exercises plus the following:** 1. Short-arc terminal extension exercise with resistance for the knee joint 2. Isometric exercise with resistance for the hamstring muscles
	Isotonic exercises: against the resistance of a standard rubber bandage

STATISTICAL ANALYSIS:

The study was conducted on 90 clinically diagnosed unilateral ACL Deficient knee subjects, they are divided in to 2 groups A and B, each group consists of 45 samples. The pre-test values of postural sway were assessed by Lords sway meter. Group A received conventional physiotherapy, Group B conventional physiotherapy with single leg dynamic balance training. for about 10 sessions. All the subjects were evaluated regarding the dependent variable before the intervention and after the completion of intervention.

To test the significant changes made from the baseline to post-test on all the groups individually statistical analysis was carried out.

A Statistical analysis of independent measures of independent t test was done in order to find out the significance in time interval within groups. Test was performed as the showed significance at 0.05 levels.

3. Results and Discussion

Within the experimental group (Group A), the joint position sense showed a significant increases from 25.4 ± 4.91 to 14.93 ± 5.22 (t = 6.653833). SEBT (Star excursion balance test) showed a raised from 77.46 ± 5.81 to 70.4 ± 2.29 (t = 6.33956), Paired t-tests confirmed significant improvements ($p < 0.05$).

In the control group (Group B), the JOINT POSITION SENSE slightly increased from 27.33 ± 5.60 to 25.6 ± 5.70 (t = 1.147768). SEBT (Star excursion balance test) shows slight change from normal level 76.33 ± 5.77 to 76.93 ± 7.27 (t = 1.974285), These changes were not significant ($p > 0.05$).

Comparing Group A and B, the JOINT POSITION SENSE difference was 10.46 ± 6.09 vs. 1.73 ± 5.84 (t = 4.09459), SEBT difference was 5.13 ± 4.24 vs. 1.4 ± 2.74 (t = 2.92621), showing significant improvements in Group A.

DISCUSSION:

This study results shows that single-leg dynamic balance training has many benefits for improving stability after ACL reconstruction. In the experimental group (Group A), there was a significant improvement in joint position sense, with scores increasing from 25.4 ± 4.91 to 14.93 ± 5.22 (t = 6.653833). Furthermore, the SEBT (Star Excursion Balance Test) scores showed extensive progressiveness from 77.46 ± 5.81 to 70.4 ± 2.29 points of which are considerable improvements These changes were statistically significant by paired t-tests ($p<0.05$) (Fong & Ng,2006)(Nam et al.,2016).

These findings support earlier work that has established the effectiveness of balance training in enhancing proprioception and functional stability(Fong & Ng,2006)(Nam et al.,2016). Gokeler et al.(2012) pointed out that balance training promotes mechanoreceptors to enhance joint position sense and thus sensory feedback crucial for maintaining stable bases are increased.In patients recovering from an ACL reconstruction it is important to improve proprioception and functional performance because they would do well on better control and confidence in daily activities as well as sports;

Joint position sense saw a slight uptick from 27.33 ± 5.60 to 25.6 ± 5.70. SEBT scores budged a tad from 76.33 ± 5.77 to 76.93 ± 7.27. These shifts didn't hit statistical significance (Nam et al. 2016). The control group's lackluster gains highlight how run-of-the-mill rehab exercises fall short in boosting proprioception and dynamic stability.

The experimental group knocked it out of the park compared to the control group. They showed way better joint position sense – the t-value of 4.09459 proves it. Their SEBT scores also left the control group in the dust. These findings point to single-leg dynamic balance training as the real MVP for upping proprioception and functional stability in ACL reconstruction recovery. It's leagues ahead of the old-school rehab methods.

The limitations of this study include the relatively small sample size and the short duration of the intervention period. Future research with larger sample sizes and longer follow-up periods could provide further insight into the long-term benefits of this training approach. In conclusion, the results of this study highlight the significant advantages of incorporating single-leg dynamic balance training into the rehabilitation process for individuals undergoing ACL reconstruction.

Reference

[1] F. N. A. Mall et al., "Incidence and Trends of Anterior Cruciate Ligament Reconstruction in the United States".

[2] J. Walker, C. Brunst, M. Chaput, T. R. Wohl and D. R. Grooms, "Integrating neurocognitive challenges into injury prevention training: A clinical commentary".

[3] Y. Ren, H. Park, Y. Wu, F. Geiger and L. Zhang, "Training for knee injury prevention using a pivoting elliptical machine".

[4] T. L. Sanders et al., "Incidence of Anterior Cruciate Ligament Tears and Reconstruction".

[5] M. M. Utukuri, H. Somayaji, V. Khanduja, G. Dowd and D. M. Hunt, "Update on paediatric ACL injuries".

[6] T. A. Lentz et al., "Return to Preinjury Sports Participation Following Anterior Cruciate Ligament Reconstruction: Contributions of Demographic, Knee Impairment, and Self-report Measures".

[7] J. C. Kennedy, H. W. Weinberg and A. S. Wilson, "The Anatomy and Function of the Anterior Cruciate Ligament".

[8] D. Kouroupis, "Mesenchymal Stem Cell Applications for Ligament Repair after Joint Trauma".

[9] Myklebust, G., & Steffen, K. (2009, June 13). Prevention of ACL injuries: how, when and who?. Springer Science+Business Media, 17(8), 857-858. https://doi.org/10.1007/s00167-009-0826-9.

[10] Gajanana Prabhu et al.(2013), Effect of Proprioceptive Exercise Training on Joint Reposition Sense and Balance of Athletes with Knee Injury Journal of Exercise Science and Physiotherapy, Vol. 9, No. 2: 89-96, 2013.

[11] Sara L.Collins et al., The incidence and etiology of ACL injuries in patients under the age of 18 in the state of Wisconsin Pediatrics and therapeutics ISSN: 2161-0665 2013

[12] Uwe Proske et al., The proprioceptive senses: Their roles in signaling body shape, body position and movement and muscle force Physiol Rev 92: 1651–1697, 2012

[13] Daina L Sturnieks et al., Validity and reliability of the Swaymeter device for measuring postural sway BMC Geriatrics 2011,11:63.

[14] Sivakumar Ramachandran et al., Measurement of Postural Sway with a Sway Meter- an Analysis J Phys Ther. 2011;2:46-53.

[15] Lee M et al., The ipsilateral motor cortex contributes to cross-limb transfer of performance gains after ballistic motor practice. J Physiol 2010;588:201–212.

[16] Alyson Filipa et al., Neuromuscular Therapy improves performance on the Star Excursion Balance Test in young female athletes. J Orthop Phys Ther 2010

[17] Zhou Mou-Warg et al.,Factors affecting Proprioceptive recovery after ACL Reconstruction. Chin Med J 2008;121(22);2224-2228

[18] Fischer et al., Proprioceptive sensitivity and performance in ACL deficient knee joint. Scandivian Journal of Medicine & Science in sports July 2008.

[19] Bohdanna T. Zazulak et al., Deficitis in neuromuscular control of the trunk predict knee injury risk. Am J Sports Med July 2007 vol.35 no.7 1123-1130.

[20] Gregory D. Myer et al., Effects of Plyometrics versus Dynamic stabilization and balnace training on lower extermitiy biomechanics. Am J Sports Med March 2006 vol.36 no.3 445-455.

[21] Timothy J. Carroll et al., Contralateral effects of Unilateral training: Evidence and possible mechanisms. J Appl Physiol 101:1515-1522, 2006

[22] Bevt. P. Mandelbaum et al., Effectiveness of Neuromuscular Control and Proprioceptive training program in preventing ACL injury in female athletes. Am J Sports Med July 2005 vol.33 no.7 1003-1010.

[23] Timothy E. Hewett et al., Knee motion and knee loading during a landing task are predictors of ACL risk in female athletes. Am J Sports Med April 2005 vol.33 no.4 492-501.

[24] B.L.Cooper Asystemic review of the effect of the Proprioception and Balance Exercises on people with an injured or Reconstructed ACL. Research in Sports Medicine, 13:163-178,2005

[25] May arna risberg et al., A systemic review of evidence for ACL rehabilitation:how much and what type? Physical Therapy in Sport 5 (2004)125-145.

[26] Gajanana Prabhu et al.(2013), Effect of Proprioceptive Exercise Training on Joint Reposition Sense and Balance of Athletes with Knee Injury Journal of Exercise Science and Physiotherapy, Vol. 9, No. 2: 89-96, 2013.

[27] Sara L.Collins et al., The incidence and etiology of ACL injuries in patients under the age of 18 in the state of Wisconsin Pediatrics and therapeutics ISSN: 2161-0665 2013

[28] Uwe Proske et al., The proprioceptive senses: Their roles in signaling body shape, body position and movement and muscle force Physiol Rev 92: 1651–1697, 2012

[29] Daina L Sturnieks et al., Validity and reliability of the Swaymeter device for measuring postural sway BMC Geriatrics 2011,11:63.

[30] Sivakumar Ramachandran et al., Measurement of Postural Sway with a Sway Meter- an Analysis J Phys Ther. 2011;2:46-53.

[31] Lee M et al., The ipsilateral motor cortex contributes to cross-limb transfer of performance gains after ballistic motor practice. J Physiol 2010;588:201–212.

[32] Alyson Filipa et al., Neuromuscular Therapy improves performance on the Star Excursion Balance Test in young female

athletes. J Orthop Phys Ther 2010

[33] Zhou Mou-Warg et al.,Factors affecting Proprioceptive recovery after ACL Reconstruction. Chin Med J 2008;121(22);2224-2228

[34] Fischer et al., Proprioceptive sensitivity and performance in ACL deficient knee joint. Scandivian Journal of Medicine & Science in sports July 2008

[35] Bohdanna T. Zazulak et al., Deficitis in neuromuscular control of the trunk predict knee injury risk. Am J Sports Med July 2007 vol.35 no.7 1123-1130.

[36] Gregory D. Myer et al., Effects of Plyometrics versus Dynamic stabilization and balnace training on lower extermitiy biomechanics. Am J Sports Med March 2006 vol.36 no.3 445-455.

[37] Timothy J. Carroll et al., Contralateral effects of Unilateral training: Evidence and possible mechanisms. J Appl Physiol 101:1515-1522, 2006.