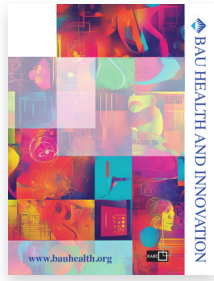
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Original Article

Comparison of Two Different Rehabilitation Approaches Applied Following Anterior Cruciate Ligament Reconstruction: A Randomized Controlled Trial

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Abstract

Objectives: This study was to investigate and analyze the effects on pain, range of motion (ROM), functional status, balance, quality of life (QOL), and kinesiophobia between a rehabilitation program including traditional physiotherapy and dual-task exercises (CP + DT) and another rehabilitation program including foam roller application in addition to traditional physiotherapy and dual-task exercises (CP+DT+FR) in patients undergoing anterior cruciate ligament reconstruction (ACL-R).

Methods: A total of 28 patients who underwent unilateral arthroscopic anterior cruciate ligament (ACL) reconstruction using hamstring tendon graft were included in this randomized controlled study. Patients who underwent ACL reconstruction for the 1st time, were in the post-operative rehabilitation phase, and were still participating in the study up to 1 year, were eligible for inclusion. Individuals with bilateral ACL injury, concomitant ligament injuries, previous knee surgery, or neurologic disorders affecting balance were excluded. Participants were divided into two groups using the randomization method, which was created by randomly drawing the group names we wrote on the papers according to their order of arrival: Traditional physiotherapy plus dual-tasking exercise group (CP+DT; n=14; mean age: 27.64 ± 6.51 years; 14 males) and traditional physiotherapy, dual-tasking and foam roller exercise group (CP+DT+FR; n=14; mean age: 23.07±3.97 years; 11 males and 3 females). All participants attended supervised rehabilitation sessions 3 times a week for a total of 8 weeks. Outcome measures were assessed at baseline and at the end of the 8-week intervention period and included measures of pain intensity, knee ROM, functional status, balance performance, QOL, and kinesiophobia.

Results: Both rehabilitation groups demonstrated statistically significant improvements in pain intensity, knee ROM, functional status, balance performance, QOL, and kinesiophobia from baseline to the end of the 8-week intervention period ($p < 0.05$). However, when between-group comparisons were performed, no statistically significant differences were observed between the CP+DT and CP+DT+FR groups for any of the outcome measures ($p>0.05$). These findings indicate that while both rehabilitation protocols were effective in improving clinical and functional outcomes following ACL reconstruction, the addition of foam roller exercises did not confer a statistically superior benefit compared with conventional physiotherapy combined with dual-task training.

Conclusion: The findings of the present study indicate that an 8-week intervention comprising conventional physiotherapy and dual-task exercises leads to significant improvements in clinical outcomes. Nevertheless, incorporating foam roller exercises into this rehabilitation protocol does not provide additional advantages with respect to pain, ROM, functionality, balance, QOL, or kinesiophobia. These results suggest that the inclusion of foam roller exercises does not appear to enhance clinical outcomes beyond those achieved with conventional physiotherapy and dual-task training within the study period.

Keywords: Anterior cruciate ligament reconstruction, exercise, outcomes, rehabilitation.

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Each year, anterior cruciate ligament (ACL) injuries occur in approximately 3% of sedentary individuals and amateur athletes; however, the incidence increases markedly, reaching up to 15% among elite athletes.[1] Notably, ACL injuries remain highly prevalent in contact sports, and despite considerable advances in research and prevention strategies, their occurrence has not significantly declined.[2]

The ACL plays an important role in the stability of the knee joint.[3] Total rupture of the ACL is considered an indication for surgery and ACL reconstruction aims to restore the joint. This goal is also shaped by the communication between the surgeon and the physiotherapist and requires the cooperation of the post-operative team because physiotherapy is the most important step for post-operative pain, swelling, loss of muscle strength, quality of life (QOL), and kinesiophobia.[4] There are also many rehabilitation methods to reduce the amount of negative effects that may occur. Some of these are cold applications, open-closed kinetic chain exercises, electrotherapy, double duty exercises, foam roller, and blood flow restriction exercises, which can be used from the 1st day.[5]

Furthermore, ACL injuries usually occur when athletes are given a second task (motor or cognitive) while they are mostly engaged in motor activity, such as landing quickly after a jump or making a difficult pass while dribbling, where decision-making is involved and creates extra load on the athlete, which can lead to an ACL tear if they are not used to it.[6] ACL tear is a knee pathology that has effects on the central nervous system's flexibility. People who have undergone ACL reconstruction (ACL-R) use cross-modal brain regions to perform knee-related movements, and their physical performance is reduced when faced with cognitive-motor dual tasks in sports or daily life. Moreover, research has shown that people who have undergone ACL-R have increased visual-cognitive neural processes to achieve motor control.[7]

Previous studies have investigated the effects of including dual-task exercises in traditional rehabilitation programs after ACL-R. In one such study, static balance performance and disability levels were assessed in individuals undergoing ACL-R, and the addition of dual-task training resulted in significant improvements in static balance.[8] While the beneficial effects of dual-task interventions have been well documented in a variety of populations, including individuals with Parkinson's disease, stroke survivors, and the elderly, evidence for their effectiveness in individuals with ACL-R remains limited. This highlights the need for further research to clarify the role of dual-task training in rehabilitation after ACL reconstruction.[9,10]

A wide range of rehabilitation modalities is continuously being introduced to facilitate return to sport following ACL injury and to reduce the risk of re-injury. Persistent deficits in muscle strength relative to pre-injury levels, along with incomplete joint range of motion (ROM), residual swelling, and pain, are among the primary factors contributing to re-injury risk.[11] In this context, foam roller application has gained increasing attention in clinical practice and has recently emerged as a popular recovery modality. Furthermore, the effects of foam roller interventions on recovery processes, physical performance, and various physiological and functional parameters have been extensively investigated in both athletic and healthy populations.[12,13]

For instance, Hajouj et al.[14] investigated the effects of adjunct rehabilitation modalities in individuals following ACL-R. In their study, one group received conventional physiotherapy alone, while the other group underwent conventional physiotherapy combined with hydrotherapy and foam roller interventions. The authors reported significant improvements in proprioceptive efficiency and neuromuscular coordination in the group receiving the combined treatment compared with conventional physiotherapy alone.[14]

However, the foam roller remains a commonly used physiotherapy modality following ACL-R and is less well documented in the literature than its clinical use. Although ACL-R rehabilitation is primarily based on traditional therapeutic approaches, the widespread clinical use of the foam roller makes it both important and necessary to investigate its effects in a structured research setting, particularly in terms of optimizing healing. However, although the acute effects of foam roller application are well known, its long-term effects have not been adequately investigated, which constitutes a limitation of the current study design.[15]

Based on the current evidence, we designed a study that integrates dual-task training with foam roller interventions in the post-operative rehabilitation period following ACL-R. The primary objective of this study is to determine whether the addition of foam roller applications to a conventional physiotherapy program combined with dual-task protocols during gait and balance training yields superior outcomes in pain modulation, joint ROM, functional performance, postural stability, QOL, and kinesiophobia when compared to a conventional rehabilitation program incorporating dual-task training alone.

Materials and Methods

Participants

This study was conducted at a private clinical center. A total of thirty-two patients who underwent unilateral arthroscopic ACL-R using a hamstring tendon autograft were included in the study.

Inclusion criteria comprised individuals aged between 18 and 40 years who had undergone unilateral ACL reconstruction and had no previous injury or surgery affecting the contralateral lower extremity.

Exclusion criteria included the presence of cardiovascular disease; a history of additional lower extremity injuries or surgeries (including revision ACL reconstruction or other knee surgeries); chronic pain requiring medication; neurological disorders that could influence balance (such as epilepsy); and concomitant posterior cruciate ligament rupture associated with the ACL injury.

Randomization

Participants were randomly assigned to one of two rehabilitation groups using a simple randomization method with sealed envelopes. A random allocation sequence was generated by preparing fourteen slips of paper labeled "CT + DT" and fourteen labeled "CT + DT + FR." These slips were randomly placed into 28 sealed and consecutively numbered envelopes by a project manager who was not involved in participant recruitment, assessment, or intervention delivery.

Participants were assigned envelope numbers from 1 to 28 according to the order in which they presented to the clinic, and group allocation was determined by opening the corresponding sealed envelope.

The first group was the conventional therapy plus dual-task group (CT + DT; n=14; age: 27.64±6.51 years; body weight: 85.50±13.72 kg), which received conventional therapy based on the accelerated rehabilitation protocol.[16] The second group was the conventional therapy, dual-task, and foam rolling group (CT + DT + FR; n=14; age: 23.07±3.97 years; body weight: 75.45±11.29 kg), which received foam rolling training in addition to the conventional rehabilitation protocol. The two groups were comparable in terms of demographic characteristics (Table 1).

Ethics Statement

All patients were informed about the research before participating in the study, and written informed consent was obtained. The ethical approval was obtained from Marmara University Faculty of Medicine Ethics Committee for Clinical Research (Protocol Number: 09.2024.370). This study was prospectively registered on Clinicaltrials.gov (NCT06831279). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Table 1. Participants' characteristics

Variables	CT+DT group (n=14) Mean±SD	CT+DT+FR group (n=14) Mean±SD	p
Weight (kg)	85.50±13.72	75.45±11.29	0.068
Height (cm)	179.92±4.54	174.92±9.65	**0.036**
Age (years)	27.64±6.51	23.07±3.97	**0.036**
BMI (kg/m^2)	26.12±4.30	24.61±2.79	0.280

SD: Standard deviation, BMI: Body mass index, CT+DT: Conventional therapy+dual task, CT+DT+FR: Conventional therapy+dual task+foam roller.

Table 2. Information on gender, operative limb, dominant limb, and type of injury

Variables	Category	CT+DT group (n=14%)	CT+DT+FR group (n=14%)	p
Gender	Female	0 (0.0)	3 (21.4)	0.22
	Man	14 (100.0)	11 (78.6)	
Operative limb	Left	7 (50.0)	7 (50.0)	1.00
	Right	7 (50.0)	7 (50.0)	
Dominant limb	Left	1 (7.1)	0 (0.0)	1.00
	Right	13 (92.9)	14 (100.0)	
Mode of injury	Contact	2 (14.3)	7 (50.0)	0.08
	Non-contact	12 (85.7)	7 (50.0)	
Type of injury	Sports competition	13 (92.9)	11 (78.6)	0.60
	Other	1 (7.1)	3 (21.4)	

CT+DT: Conventional therapy+dual task, CT+DT+FR: Conventional therapy+dual task+foam roller.

Outcome Measures and Testing Protocols

Demographics of the patients such as medical history, age, gender, height, weight, and body mass index (BMI) were recorded. In addition, information regarding gender, operative limb, dominant limb, and type of injury was also collected (Table 2). The following were measured: Kinesiophobia, soreness, equilibrium, activity level, knee function, and QOL throughout the evaluation.

Pain Level

Visual Analog Scale (VAS) is a psychometric measurement tools that allow the severity of a subjectively experienced symptom in an individual to be quantified.[17] A 100 mm paper was given for pain assessment. One end of the paper was labeled "no pain-0," and the other end was

labeled "the most severe pain possible-100." The patient was asked to mark a point on the line according to their current pain level.[18]

Activity Level

The Tegner Activity Score was used to measure the activity level of patients. The range was measured numerically related to physical activity. It is classified from 0 to 10. The lower points figure shows bad activity owing to injury, while the higher points figure shows a good activity level.[19]

Knee Function

The Lysholm Knee Scoring Scale was used to measure the functionality of the knee of patients. It consists of questions asked specifically of the patient with pain and instability. Lysholm's knee scale consists of eight items. This range scopes between 0 and 100 points. The higher the points are the far better the knee functions.[20] Out of 100 points, 95–100 points are considered excellent, 84–94 points are considered good, 65–83 points are considered average, and <65 points are considered bad.[19] The Turkish validity and cultural adaptation of the Lysholm knee score was provided by Celik et al.[20]

Balance Assessment (Star Excursion Test)

Athletes reached with their feet to the star-shaped directions drawn on the ground at a 45° angle, totaling 8 directions, and the distance they could reach was noted in cm. Balance score was measured with the formula "distance/leg length × 100."[17]

QOL

The ACL-QOL survey was used to measure the QOL. The ACL-QOL range represents subjective, patient-based, and disease-related questions. The scale includes five different items, and the higher the scores are, the better the QOL is.[19] ACL-QOL; These 5 items are in the field of symptoms and physical complaints, and also work-related. It is a scale specific to ACL injuries that examine 5 main topics with 32 questions: 4 questions in the field of concerns, 12 questions in the field of hobbies, sports, or participation in competitions, 6 questions in the lifestyle field, and 5 questions in the social and emotional field. The Turkish validity and reliability were determined by Kinikli et al.[21]

Kinesiophobia

Kinesiophobia (fear of movement) was observed by using the Tampa Scale of Kinesiophobia. Accordingly, the overall score can be scoped from 17 to 68 points. A higher score holds out higher perceived levels of kinesiophobia while lower score exhibits lower fear of mobility.[22] The scale utilizes a 4-point Likert scale (1=I completely disagree, 4=I completely agree). A total score is measured after reversing items 4, 8, 12, and 16. Its validity and reliability in Turkish were conducted on MS patients and it is still a widely used scale today. TSK is a 17-question checklist and is utilized in acute and chronic low back pain, fibromyalgia, musculoskeletal injuries, and whiplash-related diseases.[23]

Treatments

All patients underwent a pre-test, an 8-week rehabilitation exercise program, and post-test. Pre-test was performed by the physiotherapist and the doctor, after the ACL surgery was performed. At the beginning of treatment, subjects were assigned to two different groups according to their order of arrival. The CT + DT group continued to receive conventional rehabilitation, including walking, strengthening with a dual task balance exercise (60–75 min). Each conventional therapy session consisted of ROM exercise, closed kinetic chain exercise, open kinetic chain exercise, weight-bearing exercise, and dual task exercise. Elevation, cold application, ankle pump exercise, patellar mobilization, and bandaging were performed to reduce inflammation in the early post-operative period. Ice was applied 3 times daily for 30 min each application. Ankle pumping exercise was performed 5 times a day with 3 sets of 10 repetitions. Patellar mobilization was performed 3 times a day, 2 sets of 10 repetitions, superior and inferior starting from the 1st week after surgery. The ROM exercise is aimed at gaining full ROM in 8 weeks and accelerating recovery.

The 1st week was designed to increase ROM to 90°. Flexion was performed while lying down or sitting. At the end of the 4th week, flexion progressed from 90° to 130°. By the completion of the 8th week, flexion was completed to 130°. All ROM exercises were performed 3 times a day with 2 sets of 10 repetitions. Neuromuscular Electrical Stimulation (NMES) was started on the 1st post-operative day for quadriceps inhibition. NMES was given together with the straight leg raising exercise and terminal knee extension. NMES was performed at 2500 Hz in each session. It was applied with the patient lying supine for 10 s/50 s of extension and 10 s of contraction. The consistency of the stimulation was adjusted by the physiotherapist as to the patient's tolerance in each session, aiming to maximize the distribution of the motor unit. Voluntary participation was encouraged to activate their quadriceps muscles throughout the process, and the maximum limit was 120 mA. All patients showed compatibility during the sessions in the past 4th week. Hence, quadriceps strength was completed, and electrotherapy stopped in the 4th



Figure 1. Rehabilitation Exercise Program. (1) Neuromuscular electrical stimulation therapy, (2) Q-set exercise, (3) Foam roller exercise, (4) Straight leg raise, (5) Bridge exercise, (6) Stretching (hamstring femoris), (7) Heal side, (8) Lunge, (9) Clamshell exercise, (10) Patellar mobilization.

week. Strengthening exercises started on the 1st day after the surgery. In this process, which started with isometric exercises, closed kinetic chain exercises started when the muscles reactivated. After strengthening the muscles with closed kinetic chain exercises for 4 weeks, open kinetic chain exercises increased.

All strength exercises were performed 3 times a day, 2 sets of 10 repetitions. Dual-task exercises started on the 1st day after surgery. In the 1st week, while using crutches or a walker, the patient was asked to describe daily events, pictures placed in front of them, count rhythmically, and spell words. These exercises were performed on a stable surface in the 1st weeks, but after week 4, patients were asked to perform them on unstable ground or during balance exercises. The dual-task exercise was incorporated into the walking and balance exercises and practiced three times a week for approximately 15–20 min.

The CT + DT + FR group received the same traditional and dual-task rehabilitation in addition to foam roller training. All patients in this group received treatment using the foam roller used in the study. With the patient sitting upright in bed, the foam roller was placed just above the hip joint (above the ischial tuberosity). The patient lifted their hips with the help of their hands, and the foam roller was rolled up to just above the knee joint. After this stage, the rolling was continued back to the starting point. Rolling was performed at a frequency of 5 cycles/min in week 1, with each roll lasting 1.5 s. The number of cycles was increased by 10 repetitions each week. Rounding times were monitored with a cell phone stopwatch. The exercises were performed under the supervision of a physiotherapist to prevent loss of balance during the movement (Fig. 1). Dual-task exercises; in the first stage, the number recorded during walking was asked to be said again after a certain period of time. Sometimes, they were asked to count rhythmically, perform an auditory Stroop test, and sometimes to talk about daily life. The above-mentioned was started with a fixed floor and then switched to a moving floor as the weeks progressed. The progression of the traditional training protocol is presented in Table 3.

Statistical Analysis

The analysis was conducted using IBM Statistical Package for the Social Sciences Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). All data are presented as mean and standard deviation. Qualitative variables were stated from the perspective of proportions and the contrast between two proportions was tested with the Chi-square or Fisher's exact test, relying on applicability. The normality of

Table 3. Conventional physiotherapy and dual-task exercises

Clinical physiotherapy	
0–4 weeks	4–8 weeks
1. Ice (3 times* 30 min) and elevation	1. Closed kinetic chain (squat, squat with Wall)
2. Ankle pump exercise	2. Straight leg raise with resistance
3. Range of motion (0–90°)	3. Range of motion (0–130°)
4. Stretching (hamstring femoris and quadriceps muscle)	4. Leg curl (non-weight and also weight)
5. Weight shifting	5. Lunge exercise and side lunge exercise
6. Muscle strength (Q-set, straight leg raise, leg extension)	6. Bridge exercise
7. Close kinetic chain (heel raise, gait retraining)	7. Clamshell exercise
Dual Task (0–4 weeks)	Dual Task (4–8 weeks)
8. While performing walking exercises on a stable surface with crutches, the patient was asked to say the color written in a circle (Auditory Stroop test) in front of the visuals shown.	8. The patient was asked to repeat the numbers and letters that were said after a certain period of time. (movable surface)
9. The patient was asked to repeat the numbers and letters said after a certain period of time.	9. The patient was asked to spell the words, describe a picture shown, count numbers rhythmically, etc. (movable surface)
10. The patient was asked to spell words and count numbers rhythmically.	10. The patient was asked to say words that started with the specified letter, such as a city, animal, plant, object (movable surface)
11. The patient was asked to narrate his daily routine and interpret a simple daily event	11. The patient was asked to narrate his daily routine and to interpret a simple daily event. (movable surface)

distribution of all outcome variables was using the Shapiro–Wilk test. Mann–Whitney U test was used to compare quantitative variables. All statistical analyses were two-sided and carried out at a significance level of alpha =0.05.

Results

A total of 32 patients were screened in the first phase. However, three patients did not meet the criteria to continue treatment, and as a result, twenty-nine screened patients were randomized into two groups. After this process, one patient from the CT + DT group was excluded from the study because they did not attend the control examinations. Thus, the study ended with fourteen patients in the CT + DT group and fourteen patients in the CT + DT + FR group. Furthermore, the flowchart showing the criteria, excluded patients, and the groups in which the information was presented is presented in Figure 2. In addition to the flowchart, the table above showing the anthropometric characteristics (i.e., age, height, weight) of the subjects can be seen in Table 1.

In both treatment groups, there were significant differences ($p<0.05$) in VAS, ROM (flexion, extension), Lysholm score, Star movement test score, QOL, and kinesiophobia before and after the intervention. There was a significant difference in Tegner score before and after treatment in the first group, while no significant difference was observed between before and after treatment in the second group ($p=0.390$) (Table 4).

The recovery VAS ($p=0.489$), extension gain ($p=0.582$), and star movement test score of the second group (CT + DT + FR) were slightly higher than those of the first group (Fig. 3). However, this difference was not statistically significant. In contrast, the flexion degree gain, Tegner score, and QOL were slightly higher in the first group than in the second group. However, this difference was again not statistically significant (Table 4). In summary, no significant difference was observed between the two groups in all variables ($p>0.05$).

Discussion

The aim of this study was to comparatively examine the effects of dual-task exercise training during gait and balance exercises in addition to the traditional rehabilitation protocol on pain, ROM, functionality, QOL, and fear of movement in individuals with ACL-R.

The primary hypothesis of the study was that the use of foam rollers as an innovative approach would be more effective compared to the group without foam rollers. Accordingly, the study evaluated an effective exercise program and innovative approaches aimed at accelerating the healing process and increasing functional gains in ACL injuries, one of the most common injuries of the knee joint.

The findings showed that there was no statistically significant difference between the group using foam rollers and the group not using foam rollers. In other words, improvement was observed in both groups; however, the

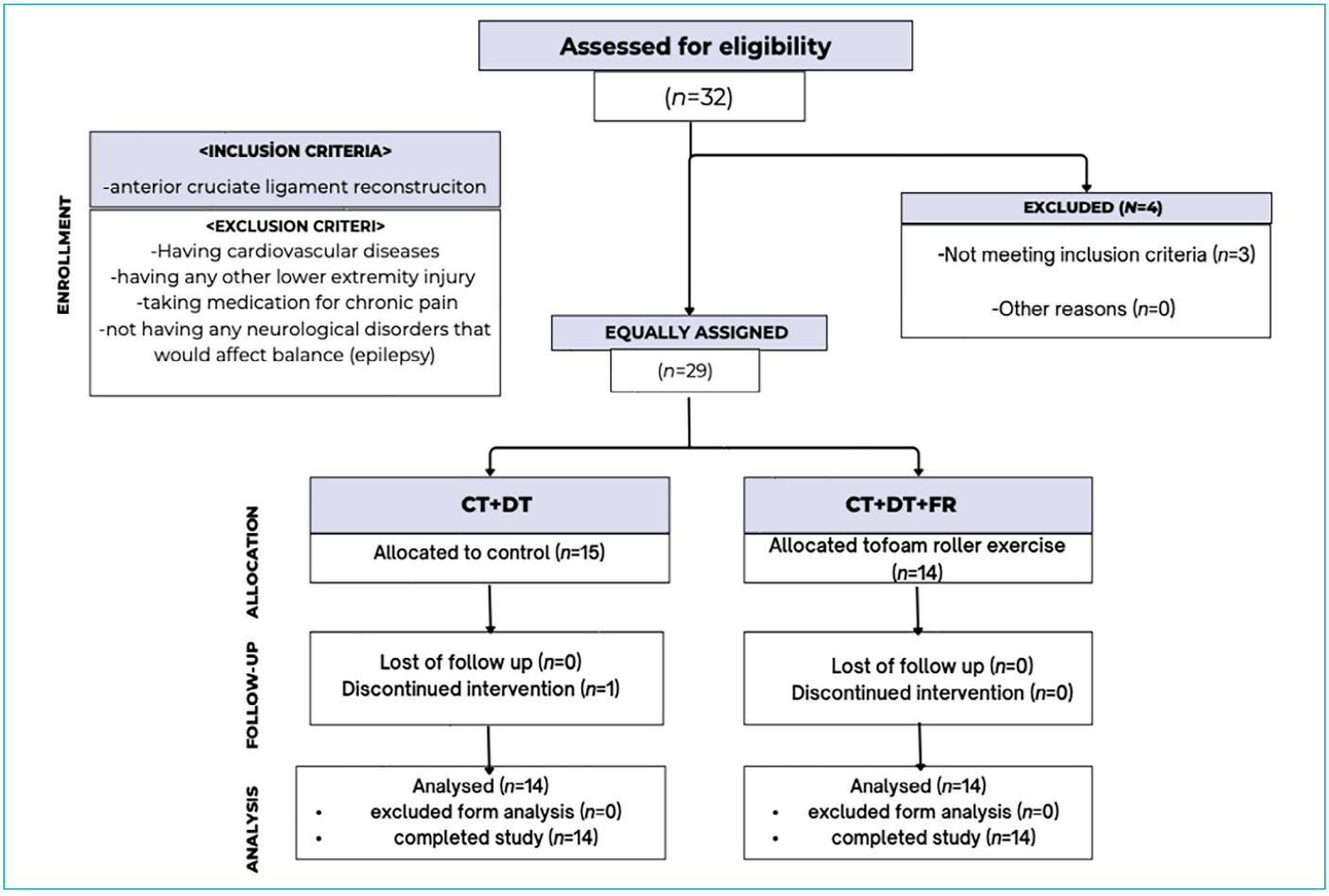


Figure 2. CONSORT flowchart.

CT+DT: Conventional and dual task rehabilitation exercise group, CT+DT+FR: Conventional rehabilitation program, dual task rehabilitation exercise, and foam roller treatment group.

innovative approach involving the use of foam rollers was not superior between the groups.

This result is in accordance with some studies in the literature. Indeed, there are studies demonstrating the effectiveness of dual-task exercises on balance and motor control.[24] In addition, in a study in which foam rollers were used during hydrotherapy, the main aim of the program was to increase neuromuscular control and reduce pain, and it was reported that this approach applied in addition to the traditional physiotherapy program increased proprioceptive efficiency.[14]

However, findings regarding the effects of myofascial release techniques such as foam rolling on short-term performance are inconsistent in the literature. Some studies report that these techniques reduce pain, increase muscle length, and ROM in the acute period.[25] On the other hand, some studies suggest that such interventions do not provide a significant advantage in long-term functional outcomes.

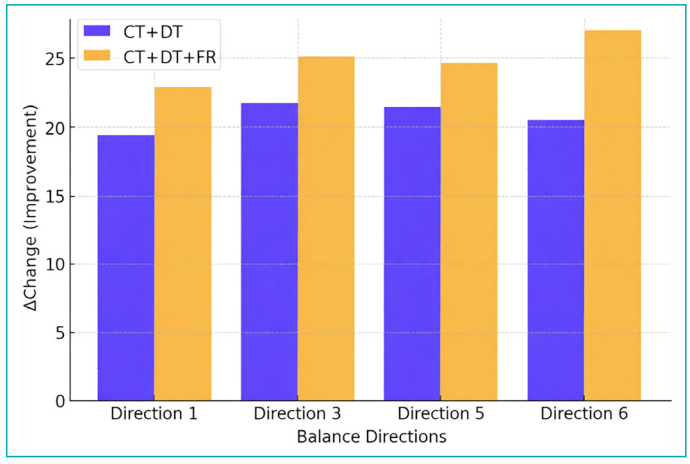


Figure 3. Star excursion balance test improvement comparison.

In this study, significant improvements in balance parameters were observed in both groups. Dual-task exercises are thought to improve adaptive responses by simultaneously challenging balance and activating the

Table 4. Change in the pain, range of motion, functionality, quality of life, and kinesiophobia score through 8-week rehabilitation intervention in each group

Variable pain (score)	Baseline, Mean±SD	8th week±SD	p_1	Δchange	p_2
CP+DT	86.92±17.40	18.35±13.95	**0.001**	-68.57±21.52	0.489
CP+DT+FR	87.14±17.17	16.78±18.35	**0.001**	-70.35±21.87	
Range of motion – Flexion (value)					
CP+DT	73.42±27.44	115.50±8.20	**0.001**	42.07±23.53	0.782
CP+DT+FR	79.28±24.87	115.21±13.62	**0.001**	35.92±17.23	
Range of motion –Extension (value)					
CP+DT	-6.57±7.79	-2.50±2.59	**0.027**	4.07±5.66	0.582
CP+DT+FR	-7.28±8.09	-1.42±3.05	**0.017**	5.85±7.40	
Functionality – Tegner (score)					
CP+DT	0.78±1.88	2.35±0.92	**0.015**	1.57±2.10	0.077
CP+DT+FR	2.35±0.92	2.00±0.78	0.390	-0.21±3.62	
Functionality – Lysholm (score)					
CT+DM	26.50±13.29	62.78±9.64	**0.001**	36.28±10.99	0.872
CT+DM+FM	28.50±19.81	61.07±12.24	**0.002**	32.57±19.96	
Quality of Life (score)					
CP+DT	12.83 ±12.10	66.55±17.96	**0.001**	53.72±18.04	0.073
CP+DT+FR	18.07±18.38	63.14±19.15	**0.001**	45.07±11.43	
Kinesiophobia (value)					
CP+DT	47±8.18	34.71±5.34	**0.001**	-12.28±4.95	0.489
CP+DT+FR	45.57±10.36	37.00±5.06	**0.016**	-8.57±10.27	

p_1: Values indicate within-group pre- and post-intervention comparisons performed using the Wilcoxon Signed-rank Test, p_2: Values indicate between-group comparisons performed using the Mann–Whitney U Test. CT+DT+FR: Conventional therapy+dual task+foam roller.

executive functions of the brain. This may contribute to the formation of a more effective and efficient postural control mechanism. Indeed, there are studies in the literature supporting that dual-task exercises positively affect balance performance in ACL-R.[26]

Recent studies have shown that psychological factors complicate the return to sports in ACL injuries and that gait and postural strategies adopted by individuals with a protective instinct may negatively affect knee joint biomechanics. In this study, a significant decrease in kinesiophobia levels was found in both groups.[27]

It is thought that foam roller applications may have reduced the perceived threat level by providing physical relaxation through muscle relaxation and proprioceptive stimulation. In addition, it can be said that dual-task exercises contribute to the suppression of fear-related responses by distracting attention from physical symptoms and thus help to reduce the fear of movement.

A statistically significant decrease in pain levels was observed in both groups. This finding is thought to be related to the analgesic and healing effects of traditional physiotherapy approaches. Although foam roller applications had pain-reducing effects in the acute period, this effect was not statistically significant in group comparisons.

The increase in ROM values indicates that muscle activation improved in both groups. It was determined that dual-task exercises supported motor control, and foam roller applications supported the flexibility of the musculoskeletal system.

After rehabilitation, an increase in the level of participation in activities of daily living was observed. It was determined that the improvement in functionality was especially associated with an increase in mobility. However, there was no statistically significant difference between the groups in terms of these parameters.

Limitations of the study include the small sample size and the single-center design, which restrict the generalizability of the findings. Although baseline differences in certain physical parameters (such as weight and BMI) were not statistically significant, they may still have influenced treatment responses. The relatively short duration of the intervention and potential variability in the standardization of foam roller application (pressure, duration, and frequency) further limit the interpretation of long-term

effects. Larger multicenter studies with extended follow-up periods are needed to validate these results.

The main strengths of this study include the fact that the interventions were implemented under controlled conditions and that all rehabilitation processes were conducted by the same therapist/team. This approach increased the consistency of the intervention and contributed to the reduction of intervention-related variability.

In the study, multidimensional assessments covering physical, functional, and psychological domains were performed, and clinically important parameters such as pain, ROM, balance, functionality, QOL, and kinesiophobia were considered together. This comprehensive assessment approach reveals not only the physical but also the psychological and functional aspects of the rehabilitation process in a holistic manner.

In addition, the dual-task exercise approach, which has been addressed in a limited number of studies in the literature on ACL rehabilitation, was integrated into the traditional rehabilitation protocol. In addition, the evaluation of foam roller application in addition to dual-task exercises offers an innovative approach that is rare in the existing literature. In particular, the comprehensive examination of parameters such as kinesiophobia, balance, functionality, and QOL with dual-task exercises and foam roller application shows that the study makes a unique contribution to the literature.

The findings of this study revealed that the traditional rehabilitation program and dual-tasking exercise approach did not provide any additional superiority in terms of pain, ROM, functionality, balance, QOL, and kinesiophobia compared to foam roller therapy applied in addition to the same interventions in individuals with ACL-R.

In the existing literature, there is no consistent consensus on the effectiveness of both dual-task exercises and foam roller applications. In this context, the addition of supportive approaches such as dual-tasking exercises or foam rolling to rehabilitation programs should be planned in line with the clinical characteristics, functional requirements, and treatment goals of individuals.

It is suggested that further studies with larger sample sizes and longer follow-up periods are needed to increase the generalizability of the findings and to demonstrate the long-term effects more clearly.

Conclusion

Dual-task exercises are preferred as a complementary rehabilitation method to traditional physical therapy approaches after ACL-R, due to the decrease in proprioceptive and kinesthetic functions and increased reliance on visual feedback in the operated limb compared to the contralateral healthy limb.

This study was designed to evaluate the effects of dual-task exercises and foam rolling intervention, applied in addition to traditional physical therapy, on pain, ROM, functionality, balance, QOL, and kinesiophobia.

The study results showed statistically significant improvements between pre- and post-intervention measurements in both regular exercise groups; however, no significant difference was found, indicating the superiority of one approach over the other when comparing the groups.

Disclosures

Ethics Committee Approval: The study was approved by the Marmara University Faculty of Medicine Clinical Research Ethics Committee (no: 09.2024.370, date: 25/05/2024).

Informed Consent: Written informed consents were obtained from patients who participated in this study.

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