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Original Article

Enhancing Recovery Outcome: The Role of Time-Based Rehabilitation Protocol in Post-Arthroscopic Anterior Cruciate Ligament Reconstruction

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Abstract

Introduction: Knee injuries are prominently ranked as the second most common type of musculoskeletal injuries in football, with anterior cruciate ligament (ACL) rupture being the most frequent. The incidence of ACL injuries is estimated to range between 100,000 to 200,000 annually worldwide, with a higher prevalence in younger, active populations. The injury often results from non-contact mechanisms involving sudden deceleration, pivoting, or awkward landings, leading to knee instability and functional impairment.

Aim of the Work: To gather evidence on the effectiveness of time based rehabilitation program in terms of return to full range of motion (ROM), muscle strength, flexibility and agility in rehabilitation of patients undergoing arthroscopic anterior cruciate ligament reconstruction.

Patients and Methods: After obtaining written, informed consent, 50 male patients (Athletes), clinically diagnosed as having anterior cruciate ligament injury, attending the outpatient clinics of Rheumatology, Physical Medicine and Rehabilitation Department during the period of April 2021 to January 2024; undergone arthroscopic ACL reconstruction surgery by same surgeon were included in the study. All patients were subjected for Time based rehabilitation protocol.

Results: The mean limb length for patients was 110.4 ± 1.81 cm. The average height of patients in meters was 1.73 ± 0.04 meters. The mean weight of patients in kilograms was 70.06 ± 3.17 kilograms. Finally, the average BMI of study subjects was 23.45 ± 1.2. The knee extension deficit in injured limb and its evolution throughout rehabilitation protocol phases. Patients showed high significant differences in knee extension over protocol phases, but there was no significant difference at 1 month postoperative period. The improvement of knee flexion in patients all over the rehabilitation protocol phases in with high significant differences. All variables showed high significant differences in muscle strength over phases. All variables that were repeatedly measured showed high significant differences in Flexibility test over protocol phases. The mean Barrow agility test was 27.8 ± 2.61 with median 27.5.

Conclusion: This study has provided valuable insights into the efficacy of the rehabilitation program for patients undergoing arthroscopic anterior cruciate ligament (ACL) reconstruction surgery. Our findings demonstrate that a structured rehabilitation regimen significantly contributes to the long-term success of ACL reconstruction, with measurable improvements in key functional outcomes

Key words: ACLR, ACL Rehabilitation, Arthroscopic Surgery, Time based rehabilitation protocol.

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Introduction

Knee injuries are prominently ranked as the second most common type of musculoskeletal injuries in football, with anterior cruciate ligament (ACL) ruptures being the most frequent.[1] The incidence of ACL injuries is estimated to range between 100,000 to 200,000 annually worldwide, with a higher prevalence in younger, active populations. The injury often results from non-contact mechanisms involving sudden deceleration, pivoting, or awkward landings, leading to knee instability and functional impairment.[2]

The ACL is critical among the four major ligaments, functioning to mitigate stress on the knee joint by stabilizing it against the forces of anterior tibial translation and internal tibial rotation.[3] An ACL injury typically results in disuse atrophy of thigh muscles, destabilization of the knee joint, diminished nerve root control, and a reduced range of active motion in the joint. [4]

ACL reconstruction surgery, typically performed arthroscopically, is considered the gold standard for managing complete ACL tears, particularly in active individuals who wish to return to sports or high-demand activities. The surgical technique involves replacing the torn ACL with a graft. While surgical advancements have improved graft fixation and reduced complications, successful recovery depends significantly on a comprehensive and well-structured rehabilitation program.[5]
The priority of post ACL reconstruction surgery rehabilitation protocols is to achieve full passive knee extension, supporting immediate weight-bearing as tolerated, and promoting functional exercises. Studies by ***Gupta et al.***[6] indicate that such accelerated rehabilitation strategies are not harmful.
Rehabilitation following ACL reconstruction arthroscopic surgery is crucial for restoring knee function, strength, stability, and proprioception. A well-designed rehabilitation program facilitates tissue healing, minimizes complications such as joint stiffness and muscle atrophy, and promotes early and safe return to daily activities and sports. The rehabilitation process is typically divided into phases, starting with immediate postoperative management, progressing to strength training, functional exercises, and finally, sport-specific training.[7]

The literature often outlines time-based rehabilitation protocols that align with the graft's remodeling process.[8] However, given the persisting uncertainties around the timing of human tissue remodeling, there is a growing preference for incorporating functional, goal-based criteria within these protocols.[9]

The main goals of rehabilitation following ACL reconstruction is to restore mobility and muscle function, with a view to facilitate the return to sports activities. Consequently, the role of rehabilitation is pivotal in determining the pace and safety with which an athlete can return to sports. [10]

Aim of the work:
To gather evidence on the effectiveness of time based rehabilitation program in terms of return to full range of motion, muscle strength, flexibility and agility in rehabilitation of patients undergoing arthroscopic anterior cruciate ligament reconstruction.

Patients and Methods:

Design: A prospective clinical study.
Patients: After obtaining written, informed consent, 50 male patients (all are football players), clinically diagnosed as having anterior cruciate ligament injury, attending the outpatient clinics of Rheumatology, Physical Medicine and Rehabilitation Department during the period of April 2021 to January 2024; undergone arthroscopic ACL reconstruction surgery by same surgeon were included in the study. All patients were subjected for Time based rehabilitation protocol. [11, 12]

Inclusion criteria:
Patients whom participated in this study underwent pre-operative rehabilitation program with minimal knee effusion and full extension, good patellofemoral mobility and the patient can actively control the quadriceps.
Have an ACLR with an autologous hamstring (HT) graft, age range from 18 - 28 years old, football players or demanding work, perform physically with no other ligamentous injury, no menisectomy previous to or simultaneous with ACLR or no cartilage damage.

Exclusion criteria:
Patients were excluded if they were younger than 18 or older than 28 years old, have ACLR with any graft other than hamstring (HT) graft, have ACL revision surgery, have other knee injury, had meniscal repair simultaneously with ACLR or have cartilage damage.

Methods:
1. Key activities in Time-based rehabilitation program [11,12] following arthroscopic ACL reconstruction surgery includes pain and swelling management, progressive range of motion exercises, weight-bearing as tolerated, and early activation of quadriceps. Strengthening exercises for the quadriceps, hamstrings, and gluteal muscles are gradually intensified, alongside balance and proprioception training. Cardiovascular conditioning begins with low-impact exercises, progressing to jogging, plyometrics, and agility drills. Functional and sport-specific drills, including cutting and pivoting, are introduced as strength and stability improve, with ongoing assessments to ensure safe return to high-level activities.
2. Patients are assessed for limb length, height, weight and BMI.
3. Assessment of range of motion (flexion & extension) by universal goniometer (UG) [13]
4. Assessment of quadriceps strength by using Dynamometer. [14]
5. Assessment of flexibility by using sit and reach flexibility test. [15]
6. Assessment of agility by using Barrow test. [16]

Results
Fifty adult male patients whom are football players were recruited from Sohag University Hospitals diagnosed as having anterior cruciate ligament injury to undergo time based rehabilitation program after anterior cruciate ligament reconstruction (ACLR).
The mean age for our sample in 23.28 ± 3.3 years. The average duration between injury and surgery was 1.56 ± 0.5 months with average rehabilitation program duration 27.6 ± 2.68 weeks.
The mean limb length for patients was 110.4 ± 1.81 cm. The average height of patients in meters was 1.73 ± 0.04 meters. The mean weight of patients in kilograms was 70.06 ± 3.17 kilograms. Finally, the average BMI of study subjects was 23.45 ± 1.2 (**Table 2**).

Table 3 was used to define knee extension deficit in injured limb and its evolution throughout rehabilitation protocol phases. We compared knee extension at preoperative period with same variable at 2, 4 & 6 months postoperative rehabilitation protocol. All variables that were repeatedly measured showed high significant differences in knee extension over protocol phases, but there was no significant difference at 1 month postoperative period.

Our research showed improvement of knee flexion in the patients all over the rehabilitation protocol phases in comparison with preoperative period evaluation with high significant differences in knee extension over all protocol phases when compared with preoperative period (**Table 4**).

Table 5 describes the evaluation of quadriceps muscle strength in injured limb by using dynamometer device and its evolution throughout rehabilitation protocol phases. We compared muscle strength at preoperative period with same variable at 1, 2, 4 & 6 months postoperative rehabilitation protocol. All variables that were repeatedly measured showed high significant differences in muscle strength over phases.

We compared Flexibility test at preoperative period with same variable at 2, 4 & 6 months postoperative rehabilitation protocol. All variables that were repeatedly measured showed high significant differences in Flexibility test over protocol phases (**Table 6**).

The mean Barrow agility test was 27.8 ± 2.61 with median 27.5 and range from 24 to 32 seconds.

Table 1: Demographic data

Demographics		**Mean** ± SD	**Median**
Age (years)		23.28 ± 3.36	23
Time Since Injury (months)		1.56 ± 0.5	2
Rehabilitation Program Duration (weeks)		27.6 ± 2.68	27
Demographics		**Frequency**	**%**
Gender	Male	50	100%
	Female	0	0%
Marital Status	Single	43	86%
	Married	7	14%
Injured Limb	Right	29	58%
	Left	21	42%

Table 2: Anthropometrics

Anthropometrics	**Mean** ± SD	**Median**
Limb length (cm)	110.4 ± 1.81	110
Height (m)	1.73 ± 0.04	1.73
Weight (kg)	70.06 ± 3.17	70
BMI	23.45 ± 1.2	23.35

Table 3: Comparison of Knee Extension deficit preoperative, 1, 2, 4 and 6 months postoperative:

Knee Extension	**Mean**	**SD**	**T Test**	**P Value**
Knee extension (°) – preoperative	2.356	3.40	0.444	0.659
Knee extension (°), deficit – at 1 month postoperative	2.268	3.60		
Knee extension (°) – preoperative	2.356	3.40	11.5	< **0.001**
Knee extension (°), deficit – at 2 month postoperative	2.215	8.70		
Knee extension (°) – preoperative	2.356	3.40	5.011	< **0.001**
Knee extension (°), deficit – at 4 month postoperative	2.020	1.00		
Knee extension (°) – preoperative	2.356	3.40	7.624	< **0.001**
Knee extension (°), deficit – at 6 month postoperative	0.5	1.52		

Table 4: Comparison of Knee Flexion deficit preoperative, 1, 2, 4 and 6 months postoperative:

Knee Flexion	**Mean**	**SD**	**T Test**	**P Value**
Knee Flexion (°) – preoperative	3.446	135.60	34.870	< **0.001**
Knee Flexion deficit (°) - at 1 month postoperative	4.849	106.40		
Knee Flexion (°) – preoperative	3.446	135.60	25.535	< **0.001**
Knee Flexion deficit (°) - at 2 month postoperative	3.747	116.80		
Knee Flexion (°) – preoperative	3.446	135.60	10.473	< **0.001**
Knee Flexion deficit (°) - at 4 month postoperative	3.104	128.40		
Knee Flexion (°) – preoperative	3.446	135.60	0.7025	< **0.001**
Knee Flexion deficit (°) - at 6 month postoperative	2.558	139.70		

Table 5: Comparison of Quadriceps Muscle Strength Testing preoperative, 1, 2, 4 and 6 months postoperative:

Quadriceps Strength Testing	**Mean**	**SD**	**T Test**	**P Value**
Dynamometer, injured limb (Kg) – preoperative	17.88	1.32	40.750	< **0.001**
Dynamometer, injured leg (Kg) - at 1 month postoperative	8.90	0.89		
Dynamometer, injured limb (Kg) – preoperative	17.88	1.32	37.249	< **0.001**
Dynamometer, injured leg (Kg) - at 2 month postoperative	10.74	0.9		
Dynamometer, injured limb (Kg) – preoperative	17.88	1.32	4.705	< **0.001**
Dynamometer, injured leg (Kg) - at 4 month postoperative	16.96	0.93		
Dynamometer, injured limb (Kg) – preoperative	17.88	1.32	34.132	< **0.001**
Dynamometer, injured leg (Kg) - at 6 month postoperative	24.94	0.79		

Table 6: Comparison of Flexibility Testing preoperative, 2, 4 and 6 months postoperative:

Flexibility Test	Mean	SD	T Test	P Value
Sit and reach flexibility test (cm) – preoperative	31.32	3.75	18.214	< **0.001**
Sit and reach flexibility test (cm) - at 2 month postoperative	35.30	3.42		
Sit and reach flexibility test (cm) – preoperative	31.32	3.75	24.217	< **0.001**
Sit and reach flexibility test (cm) - at 4 month postoperative	37.82	2.78		
Sit and reach flexibility test (cm) – preoperative	31.32	3.75	34.206	< **0.001**
Sit and reach flexibility test (cm) - at 6 month postoperative	40.94	2.37		

Discussion:

The anterior cruciate ligament (ACL) is the most commonly completely ruptured ligament in the knee joint. Due to its limited ability to heal on its own, surgical reconstruction is typically advised to replace the damaged ACL with either an autograft or an allograft.[5,17] Among the available graft options, hamstring tendon (HT) grafts are frequently chosen for primary ACL reconstruction because of their favorable outcomes in restoring knee stability and function. [18, 19]

The primary objective of rehabilitation following ACL reconstruction is to restore knee mobility, enhance muscle strength, and facilitate a safe and efficient return to athletic activities. [20] However, there is still a lack of consensus in the literature regarding the most effective physical therapy protocols to employ after ACL reconstruction. [7,21]

This study aimed to evaluate the impact of a time-based rehabilitation program on range of motion (ROM), muscle strength, flexibility and agility in patients who have undergone ACL reconstruction surgery with a hamstring tendon graft. A total of fifty male patients participated in this study and followed a time-based rehabilitation protocol.

The anthropometric measurements of our study subjects reveal a mean limb length of 110.4 ± 1.81 cm, an average height of 1.73 ± 0.04 meters, a mean weight of 70.06 ± 3.17 kg, and an average BMI of 23.45 ± 1.2. These measurements provide insight into the physical characteristics of our patient population and their potential influence on rehabilitation outcomes following ACL reconstruction.

Our subjects' limb length and height are comparable to those reported in similar studies. For instance, a study by ***Wright et al.*** [22] indicated that average limb lengths and heights in young adults undergoing ACL reconstruction were similar, suggesting that our sample is representative of the general population for this demographic.

Additionally, the mean BMI of 23.45 falls within the range of normal weight, which aligns with findings by ***Ninkovic et al***.[23] who noted that individuals with a BMI within the normal range often experience favorable outcomes post-surgery compared to those who are overweight or obese. The findings of our study are consistent with those of a study by ***Sliepka, et al.*** [24], which found that patients with higher BMI may face more challenges during the rehabilitation process, potentially impacting long-term success.

In our study evaluating knee extension deficits following arthroscopic anterior cruciate ligament (ACL) reconstruction, we observed a significant reduction in knee extension deficits from preoperative measurements to postoperative assessments. Specifically, the mean deficit in knee extension decreased from 2.36 ± 3.40° preoperatively to 0° at 6 months postoperative (***p < 0.001***). This aligns with findings from other studies, such as those by, ***Ektas, et al.***[25] who reported similar improvements in knee extension over a 6-month period following ACL reconstruction, with deficits decreasing from 3.0° to 0.5° (***p < 0.001***).

Additionally, ***Wierer et al.*** [26] found that knee extension deficits at 4 months postoperatively were reduced significantly from preoperative levels, although their mean residual deficit was slightly higher at 1.5° compared to our 2.02° (***p < 0.001***). Notably, our results indicate a more rapid and complete resolution of knee extension deficits by 6 months compared to the study by, ***Scholes, et al.*** [27] where residual deficits of 1.2° were still present at the 6-month mark (***p = 0.02***).

Our study demonstrates notable changes in knee flexion following arthroscopic ACL reconstruction, with significant reductions in flexion deficits from preoperative measurements to postoperative follow-ups. Specifically, preoperative knee flexion averaged 3.446°, with deficits observed at 6 months postoperative averaging 2.558° ($p < 0.001$). These findings are consistent with the results reported by ***Emami Meybodi et al.***.[28], who documented a reduction in knee flexion deficits from 3.5° preoperatively to 2.0° at 6 months postoperative (***p < 0.01***). Conversely, our results show a slightly less favorable outcome compared to those of ***Cavanaugh,***[29] who observed a more substantial improvement with postoperative flexion deficits decreasing from 4.0° to 1.5° over a similar period (***p < 0.001***).

Additionally, our findings contrast with those of ***Shelbourne, et al.*** ,[30]who noted minimal changes in flexion deficits from 3.6° preoperatively to 3.2° at 6 months (***p = 0.35)***, suggesting that their rehabilitation approach may have been less effective in improving flexion range.

In our study assessing quadriceps muscle strength in the injured limb using a dynamometer, we observed significant changes from preoperative to postoperative evaluations. Preoperatively, the mean quadriceps strength was 17.88 kg (SD = 1.32). At 1 month postoperative, the strength significantly decreased to 8.90 kg (SD = 0.89), and at 2 months postoperative, it increased to 10.74 kg (SD = 0.90). By 4 months postoperative, strength improved to 16.96 kg (SD = 0.93), and at 6 months postoperative, it reached 24.94 kg (SD = 0.79). These results highlight a notable recovery trend, although initial postoperative strength was considerably lower than preoperative levels.

These findings are consistent with the results reported by ***Ithurburnet al.,*** [31], who found similar patterns of quadriceps strength recovery following ACL reconstruction. Their study reported a preoperative mean strength of 18.2 kg (SD = 1.5) which dropped to approximately 9.5 kg (SD = 1.2) at 1 month postoperative, showing a comparable initial decrease in strength. They observed an increase in strength to 11.0 kg (SD = 1.3) at 2 months, and by 6 months, strength had improved to 23.0 kg (SD = 1.0), aligning closely with the progression seen in our study.

Similarly, a study by ***Ueda, et al.***[32] reported preoperative quadriceps strength of 17.5 kg (SD = 1.3) and a postoperative decrease to 10.0 kg (SD = 0.9) at 2 months. Their follow-up at 6 months showed an increase in strength to 25.0 kg (SD = 1.1), which is slightly higher than our findings but follows a similar trend of gradual improvement. Conversely, the study by***Curran, et al.*** [33] observed a more gradual recovery in quadriceps strength. Their preoperative measurements averaged 18.0 kg (SD = 1.4), with a postoperative strength of 12.0 kg (SD = 1.1) at 4 months and 18.5 kg (SD = 1.3) at 6 months.

In our study evaluating flexibility through the Sit and Reach Test, we observed a significant improvement in flexibility in the injured limb following ACL reconstruction. Preoperatively, the mean Sit and Reach score was 31.32 cm (SD = 3.75). At 2 months postoperative, the mean score increased to 35.30 cm (SD = 3.42), rising further to 37.82 cm (SD = 2.78) at 4 months, and reaching 40.94 cm (SD = 2.37) at 6 months.

These findings indicate substantial gains in flexibility over the postoperative period. Our results align with those reported by ***McHugh ,at al.,*** [34] who conducted a study on flexibility recovery following ACL reconstruction. Their research showed preoperative Sit and Reach scores of approximately 30.8 cm (SD = 4.0), with improvements to 34.5 cm (SD = 3.5) at 2 months and 37.0 cm (SD = 3.0) at 4 months, and an increase to 40.0 cm (SD = 2.5) at 6 months. These results support our findings, indicating that flexibility improves progressively after ACL surgery and reinforces the effectiveness of rehabilitation programs in enhancing range of motion.

Similarly, a study by ***Abrams,et al.*** .[35] reported preoperative Sit and Reach scores of 30.5 cm (SD = 3.8) and found that flexibility improved to 36.0 cm (SD = 3.2) at 2 months and 38.5 cm (SD = 2.7) at 4 months. At 6 months, their study reported scores of 41.2 cm (SD = 2.3), which is slightly higher than our findings but follows a comparable improvement trajectory. This consistency

underscores the positive impact of rehabilitation on flexibility.

In our study, the Barrow Agility Test yielded a mean score of 27.8 ± 2.61 seconds, with a median of 27.5 seconds and a range from 24 to 32 seconds. This measure of agility is crucial in evaluating functional recovery post-ACL reconstruction, reflecting both dynamic stability and coordination. These findings are consistent with research by ***Shelbourne, et al*** ,[(36)] who reported a mean Barrow Agility Test time of 28.2 seconds (SD = 2.9) in a cohort of ACL-reconstructed patients at a similar postoperative stage.

Their results, with a range of 25 to 33 seconds, closely align with our findings, indicating that agility performance in our sample is within the expected range for this population. Similarly, a study by ***Keays, et al.*** ,[(37)] observed a mean agility test time of 27.4 seconds (SD = 2.5) at 6 months postoperative. Their results are comparable to ours, supporting the notion that patients typically achieve similar agility levels within this timeframe following ACL reconstruction. In contrast, research by ***Abrams et al,.*** [(35)] reported slower agility scores, with a mean time of 30.0 seconds (SD = 3.1) at 6 months postoperative.

This discrepancy might be attributed to differences in rehabilitation protocols or the inclusion of patients with more severe impairments. ***Sonesson. et al***.[(38)]suggested that factors such as rehabilitation intensity and patient adherence could contribute to variability in agility recovery.

Conclusion:

This study has provided valuable insights into the efficacy of the rehabilitation program for patients undergoing arthroscopic anterior cruciate ligament (ACL) reconstruction surgery. Application of time based rehabilitation protocol for 24 weeks can increase range of motion of the knee, muscle strength, flexibility and agility.

The results indicate that patients, who adhered to the prescribed rehabilitation protocol exhibited notable gains in performance postoperative compared to preoperative levels.

Furthermore, our study highlights the importance of early intervention and consistent progression through the rehabilitation phases. The significant improvements observed in muscle strength and functional tests underscore the effectiveness of a well-designed rehabilitation plan in addressing the deficits caused by ACL injury and surgery. It is evident that a comprehensive approach that includes strength training, agility drills, and sport-specific exercises is vital for optimal recovery.

Recommendation:

Additional studies should be conducted to study other rehabilitation programs as conventional physical therapy program post ACL reconstruction (designed to decrease pain and effusion and increase ROM) and goal based rehabilitation protocol (designed to decrease pain and effusion, increase ROM, muscles strength functional outcome and mainly to improve the functional outcome).

Additional studies should be conducted for further injuries such as ACLR combined with meniscectomy, meniscal repair and/or collateral ligaments repair. Further studies should be conducted to investigate the criteria of returning to pre-injury level of competitive sport.

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