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ANTERIOR CRUCIATE LIGAMENT RUPTURE IN HANDBALL PLAYER – A CASE STUDY

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Abstract: *Anterior cruciate ligament rupture is one of the most serious injuries affecting handball players due to the sport's high-intensity movements such as jumping, fast changes of direction and pivoting. Most ACL injuries occur through non-contact mechanisms, particularly during landing, cutting maneuvers, or sudden deceleration, often associated with biomechanical factors like dynamic knee valgus and inadequate neuromuscular control. The etiology of ACL injuries in handball is multifactorial, involving intrinsic factors such as anatomical characteristics, neuromuscular imbalances, and previous injuries, as well as extrinsic factors including playing surface, footwear, and training load. Recent research highlights the importance of structured neuromuscular training programs designed to improve strength, proprioception, and movement mechanics in order to reduce injury risk.*

Key words: *ACL injury, handball players, recovery, neuromuscular control.*

1. Introduction

Team handball is a high-intensity intermittent sport that requires a combination of speed, power, agility, and coordination. These sport-specific actions expose the musculoskeletal system to substantial mechanical stress, particularly at the level of the knee joint, making lower limb injuries common among handball athletes [13].

The ACL is the primary stabilizing structure of the knee joint, playing a crucial role in preventing excessive anterior translation of the tibia relative to the femur and in controlling rotational stability during dynamic movements [21]. In addition, ACL injuries frequently require surgical reconstruction followed by a long and complex rehabilitation process that may last between 6 and 12 months before a safe return to sport is possible [2]. Despite advances in surgical techniques and rehabilitation protocols, many athletes fail to return to their pre-injury level of performance, and some may even be forced to end their competitive careers prematurely [22].

The epidemiology of ACL injuries has been extensively studied in sports characterized by cutting, pivoting, and jumping movements, including soccer, basketball, and handball. Research indicates that the incidence of ACL injuries

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is particularly high in team handball due to the specific biomechanical demands of the sport [18].

Injury surveillance studies have shown that knee injuries represent a significant proportion of all injuries sustained in handball players, with ACL ruptures accounting for a considerable percentage of severe injuries that lead to prolonged absence from competition [11].

Moreover, the incidence of ACL injuries appears to be higher among female athletes compared to male athletes, a difference that has been attributed to a combination of anatomical, hormonal, and neuromuscular factors [20]. These injuries are typically associated with high-risk sport-specific movements such as rapid cutting maneuvers, sudden deceleration, and single-leg landing following a jump shot [10].

Biomechanical analyses and video-based injury investigations have shown that ACL rupture often occurs when the knee is subjected to excessive valgus loading combined with internal tibial rotation and high ground reaction forces [4]. Intrinsic factors include anatomical characteristics such as increased knee valgus alignment, joint laxity, and variations in tibial slope, as well as neuromuscular deficits and muscle strength imbalances between the quadriceps and hamstring muscles [7].

Extrinsic factors also play an important role in the occurrence of ACL injuries in handball players. These factors include environmental conditions and sport-specific variables such as playing surface characteristics, footwear, level of competition, and training intensity [3].

Studies have suggested that congested competition schedules and high training loads may contribute to an increased risk of injury by reducing the capacity of athletes to maintain optimal movement mechanics throughout the game. Neuromuscular training programs that focus on improving strength, proprioception, balance, and movement technique have been shown to be effective in reducing biomechanical risk factors associated with ACL injuries [1].

Recent systematic reviews and meta-analyses have demonstrated that structured injury prevention programs can significantly reduce the incidence of ACL injuries among athletes participating in pivoting sports [17].

In handball specifically, neuromuscular training interventions have shown promising results in improving movement control and reducing injury risk during high-intensity game situations [14].

1.1. Anatomy and biomechanics

From an anatomical perspective, the knee is a synovial hinge joint that connects the femur, tibia, and patella, allowing movements primarily in the sagittal plane while also permitting limited rotational and translational movements [19].

The bones in the knee joint include the lower part of the thigh bone, the upper part of the shin bone, and the kneecap. The rounded ends of the femur fit into the flat parts of the tibia, creating the tibiofemoral joint. At the same time, the kneecap fits into the groove on the femur, forming the patellofemoral joint. The patella acts as a sesamoid bone embedded within the quadriceps tendon and serves to increase the mechanical advantage of the quadriceps muscle during knee extension. [15].

Joint stability is maintained by a complex system of passive and active stabilizing structures. Passive stabilizers include the joint capsule, ligaments, and menisci, while active stabilization is provided by the surrounding musculature, particularly the quadriceps, hamstrings, gastrocnemius, and popliteus muscles [5].

Among the passive stabilizers, the ligaments play a fundamental role in maintaining knee integrity and preventing excessive joint displacement. The knee joint includes four major ligaments: the anterior cruciate ligament, the posterior cruciate ligament, the medial collateral ligament and the lateral collateral ligament [12].

The menisci are important for how the knee works properly. The medial and lateral menisci are tough, rubbery tissues that lie between the rounded ends of the thigh bone and the flat part of the shin bone. Their main jobs are spreading out weight, cushioning the impact, keeping joints steady, and making sure the joint surfaces stay smooth and slippery [6].

By increasing the contact area between the femur and tibia, the menisci help reduce stress on the articular cartilage and contribute to overall joint stability. Knee flexion typically ranges from 0° in full extension to approximately 135° in maximum flexion. However, when the knee is flexed, small degrees of internal and external rotation can occur due to the geometry of the femoral condyles and the elasticity of the surrounding soft tissues [15].

In sports such as handball, jumping and landing movements can generate forces several times greater than body weight, placing considerable stress on the knee ligaments, particularly the ACL [9].

When excessive valgus stress, rotational torque, or anterior tibial translation occurs simultaneously, the mechanical load on the ACL may exceed its tensile strength, resulting in ligament rupture. Another important biomechanical concept associated with knee function is neuromuscular control.

Good coordination between the quadriceps and hamstring muscles is important for keeping the knee stable during intense activities. The hamstrings act as dynamic stabilizers by counteracting anterior tibial translation produced by quadriceps contraction, thereby reducing stress on the ACL [16].

1.2. Recovery objectives

Rehabilitation following anterior cruciate ligament injury or reconstruction is a complex and progressive process aimed at restoring the functional integrity of the knee joint and enabling a safe return to sport.

a) One of the first objectives of rehabilitation is the control of pain, and swelling in the acute phase following injury or surgery. Effective management of inflammation facilitates tissue healing and allows the patient to initiate early mobilization exercises. Early restoration of full knee extension and gradual recovery of flexion range of motion are essential in preventing joint stiffness and long-term functional limitations.

b) Another major objective of rehabilitation is the restoration of muscular strength and mobility joints, particularly in the quadriceps and hamstring muscle groups.

c) Improving neuromuscular control and proprioception is also a key component of ACL rehabilitation. Proprioceptive training enhances the body's ability to detect joint position and movement, which is essential for maintaining dynamic knee stability during complex motor tasks.

d) Another important objective is the progressive reintroduction of functional and sport-specific movements. This stage focuses on preparing the athlete for the physical demands of sports activities by incorporating plyometric exercises, agility drills, and cutting or pivoting maneuvers.

e) The ultimate objective of rehabilitation is to ensure a safe and effective return to sport. Before returning to competitive activity, athletes should demonstrate adequate strength, joint stability, and functional performance through objective testing. Successful rehabilitation following ACL rupture requires a comprehensive approach that addresses pain management, joint mobility, muscular strength, neuromuscular control, and sport-specific functional performance.

1.3. Recovery program

Rehabilitation following anterior cruciate ligament injury or reconstruction is essential for restoring knee stability, strength, proprioception, and functional performance. The rehabilitation process is typically structured into progressive phases, each with specific objectives and therapeutic exercises designed to promote safe and effective recovery. A well-designed rehabilitation program not only facilitates the return to sport but also reduces the risk of re-injury [2, 22].

Phase I: 0–2 weeks

The primary goals of this phase are to control pain and swelling, restore knee extension, and initiate early muscle activation. Interventions typically include cryotherapy, compression, and elevation to reduce inflammation. Passive and active-assisted range of motion exercises are performed to restore full knee extension and gradually increase flexion. Isometric exercises targeting the quadriceps and hamstrings are introduced to prevent muscle atrophy. Weight-bearing is usually allowed as tolerated, often with the assistance of crutches.

Phase II: 2–6 weeks

During this phase, the focus shifts toward improving joint mobility, increasing muscle strength, and restoring normal gait patterns. Closed kinetic chain exercises such as mini-squats, leg presses, and step-ups are commonly implemented to promote functional muscle activation while minimizing stress on the ACL. Balance and proprioceptive exercises are also introduced to improve neuromuscular control and joint stability.

Phase III: 6–12 weeks

The primary objective of this stage is to enhance muscular strength, endurance, and dynamic stability of the knee joint. Progressive resistance training is implemented for quadriceps, hamstrings, gluteal muscles, and core musculature. Exercises such as lunges, leg curls, and resistance band exercises are frequently incorporated. In addition, proprioceptive training using unstable surfaces, such as balance boards or BOSU balls, is used to further improve neuromuscular coordination.

Phase IV: 3–6 months

In this phase, rehabilitation progresses toward sport-specific training. Plyometric exercises, agility drills, and dynamic balance tasks are introduced to prepare the athlete for the demands of competitive sport. Activities such as jump training, lateral movements, and controlled cutting maneuvers are gradually integrated. These exercises aim to improve explosive strength, coordination, and movement mechanics.

Phase V: 6–9 months

The final stage of rehabilitation focuses on restoring full functional performance and preparing the athlete for safe return to sport. High-intensity sport-specific drills, including sprinting, pivoting, and jump-landing tasks, are incorporated to simulate game situations. Functional testing, such as hop tests and strength assessments, is often performed to evaluate readiness for return to play. A gradual return to full participation in training and competition is recommended to minimize the risk of re-injury [8].

A structured and progressive rehabilitation program is essential for successful recovery following ACL injury. The integration of strength training, neuromuscular control exercises, and sport-specific movements plays a critical role in restoring knee function and ensuring a safe return to athletic activity.

2. Material and Method

In this study, we used elastic bands, physiotherapy machines, mattresses, bosu balls, trx, ankle weights, jump box, flowing board, kinesiotape, myofascial tools, foam roller, trellis, sponge balls, togu ball, fitness ball, dumbbells.

Evaluation methods included magnetic resonance imaging (MRI) as well as clinical functional tests of the knee, including anterior and posterior drawer tests, Pivot-Shift test, active quadriceps test, and McMurray test.

The anterior drawer test is a standard way that doctors check the knee to see if the anterior cruciate ligament is damaged and to find out if there is instability in the front of the knee. It checks how far the shin bone moves forward compared to the thigh bone and is often used together with other tests like the Lachman test and pivot-shift test.

The pivot shift test is a movement-based check done by a healthcare professional to look for problems with the knee's stability, especially related to twisting movements. It is one of the best ways to tell if the anterior cruciate ligament in the knee is damaged.

The McMurray test is a widely used clinical examination for the detection of meniscal injuries in the knee joint.

Although it is not specific for anterior cruciate ligament rupture, it is frequently performed in the assessment of knee injuries due to the high incidence of associated meniscal lesions in patients with ACL deficiency.

Table 1

Recovery program for handball player

Recovery period	Methods and means	Objective
Phase I: 0-2 weeks	• Cryotherapy and anti-inflammatory measures • Passive and assisted ROM exercises • Isometric quadriceps and hamstring contractions • Patellar mobilization techniques	Reducing pain and inflammation Increasing range of motion
Phase II: 2-6 weeks	• Progressive ROM exercises • Closed kinetic chain exercises • Neuromuscular electrical stimulation • Gradual progression to full weight-bearing • Initiation of balance and proprioceptive exercises	Reducing pain and inflammation Increasing range of motion Increasing muscle tone
Phase III: 6-12 weeks	• Progressive strengthening exercises • Advanced closed kinetic chain exercises • Proprioceptive and balance training • Core stability exercises • Gait training and correction	Reducing pain and inflammation Increasing range of motion Increasing muscle tone Restoring muscle balance Restoring joint stability Improving neuromuscular control and proprioception
Phase IV: 3-6 months	• Advanced strength training • Plyometric exercises • Agility drills and change-of-direction training • Running progression program • Sport-specific movement pattern • Neuromuscular and proprioceptive training	Reducing pain and inflammation Increasing range of motion Increasing muscle tone Restoring muscle balance Restoring joint stability Improving neuromuscular control and proprioception Progressive reintroduction of functional and sport-specific movements.
Phase V: 6-9 months	• Plyometric training • Agility and reactive drills • Sport-specific training under game-like conditions • Functional testing • Gradual return to full training and competition	Improving neuromuscular control and proprioception Progressive reintroduction of functional and sport-specific movements. Ensure a safe and effective return to sport.

3. Results and Discussions

The rehabilitation program implemented in this study was structured into five progressive phases; each characterized by specific therapeutic methods and clearly defined objectives. The phased approach allowed for gradual recovery of knee function, ensuring both biological healing and functional adaptation to sport-specific demands.

In the initial phase (0–2 weeks), the primary focus was on pain and inflammation control, as well as the early restoration of joint mobility. The use of cryotherapy, anti-inflammatory measures, passive and assisted range of motion (ROM) exercises, and isometric muscle contractions proved effective in reducing swelling and preventing muscle atrophy.

Early patellar mobilization also contributed to maintaining joint mobility and preventing adhesion. These findings are consistent with current rehabilitation guidelines emphasizing early mobilization to optimize recovery outcomes.

During Phase II (2–6 weeks), the introduction of progressive ROM exercises and closed kinetic chain exercises facilitated improvements in joint mobility and muscle activation. Neuromuscular electrical stimulation supported quadriceps activation, particularly in cases of post-injury inhibition. The gradual transition to full weight-bearing, combined with balance and proprioceptive exercises, contributed to improved neuromuscular control and functional stability of the knee joint.

In Phase III (6–12 weeks), the emphasis shifted toward strengthening and restoring muscular balance. Progressive resistance training, along with advanced closed kinetic chain exercises, significantly improved muscle tone and joint stability. Proprioceptive and balance training, combined with core stability exercises, played a crucial role in enhancing neuromuscular coordination. Gait training further contributed to the normalization of movement patterns, reducing compensatory mechanisms that could increase the risk of re-injury.

The advanced rehabilitation phase (3–6 months) focused on preparing the athlete for sport-specific demands. The inclusion of plyometric exercises, agility drills, and running progression programs facilitated the development of explosive strength and dynamic stability. Neuromuscular and proprioceptive training during this phase was essential for improving movement efficiency and reducing biomechanical risk factors associated with ACL injury. The progressive reintroduction of sport-specific movement patterns ensured a safe transition toward higher levels of functional performance.

Finally, in the return-to-sport phase (6–9 months), the rehabilitation program emphasized high-intensity functional training under conditions that simulate real game scenarios. Plyometric training, reactive agility drills and sport-specific exercises allowed athletes to regain confidence and performance capacity. Functional testing was used to assess readiness for return to play, ensuring that athletes met the necessary criteria for safe reintegration into training and competition.

Overall, the results of this structured rehabilitation protocol demonstrate that a progressive, phase-based approach is effective in restoring knee function following ACL rupture. The integration of strength training, neuromuscular control exercises, and sport-specific activities plays a critical role in reducing the risk of re-injury and ensuring a safe return to sport. These findings agree with recent literature, which highlights the importance of individualized, criteria-based rehabilitation programs in optimizing long-term outcomes after ACL injury.

The rehabilitation program applied in this study successfully addressed the key objectives of recovery, including pain reduction, restoration of range of motion, muscle strengthening, neuromuscular control, and functional performance. The progressive nature of the program allowed for safe and effective reintegration into competitive handball, supporting its applicability in clinical and sports rehabilitation settings.

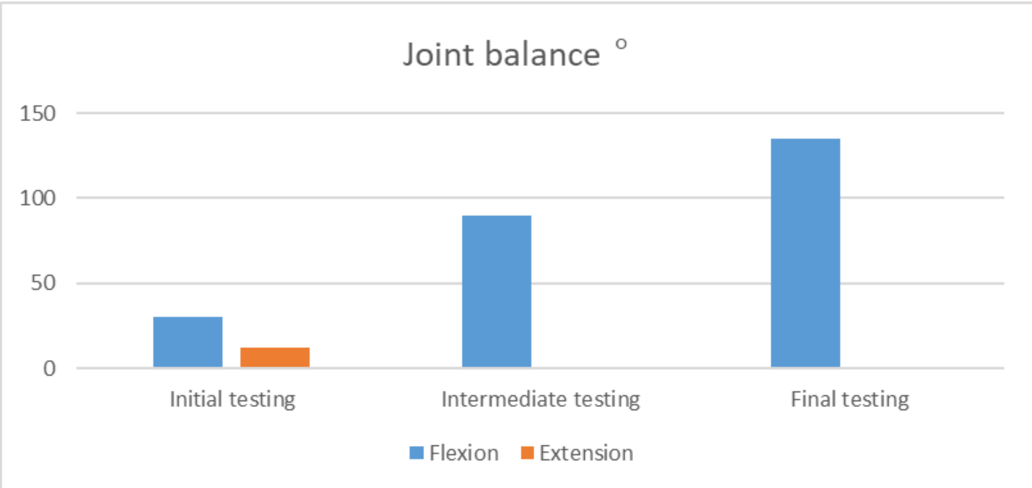

Fig. 1. *Joint balance*

The assessment of knee joint range of motion (ROM) demonstrated a significant and progressive improvement throughout the rehabilitation period. At the initial evaluation, knee flexion was limited to 30°, while extension presented a deficit of 12°, indicating considerable functional impairment typically associated with anterior cruciate ligament (ACL) injury.

These limitations are commonly attributed to pain, joint effusion, and protective muscle inhibition in the acute phase.

During the intermediate testing phase, a substantial improvement was observed, with knee flexion increasing to 90° and full extension (0°) being restored.

The recovery of full knee extension at this stage represents a critical milestone in the rehabilitation process, as it is essential for normal gait patterns and for preventing long-term complications such as joint stiffness and altered biomechanics.

By the final evaluation, knee flexion reached 135°, which corresponds to a normal physiological range, while full extension (0°) was maintained. This indicates a complete restoration of joint mobility and suggests that the rehabilitation program was effective in addressing both flexion and extension deficits.

The progressive increase in ROM reflects the successful implementation of early mobilization strategies, combined with structured therapeutic exercises.

Overall, the results demonstrate that the rehabilitation protocol facilitated a gradual and complete recovery of knee joint mobility.

The restoration of full ROM is essential not only for functional performance but also for reducing the risk of re-injury and ensuring a safe return to sport. These findings are consistent with current evidence, which highlights the importance of early extension recovery and progressive flexion gains in ACL rehabilitation.

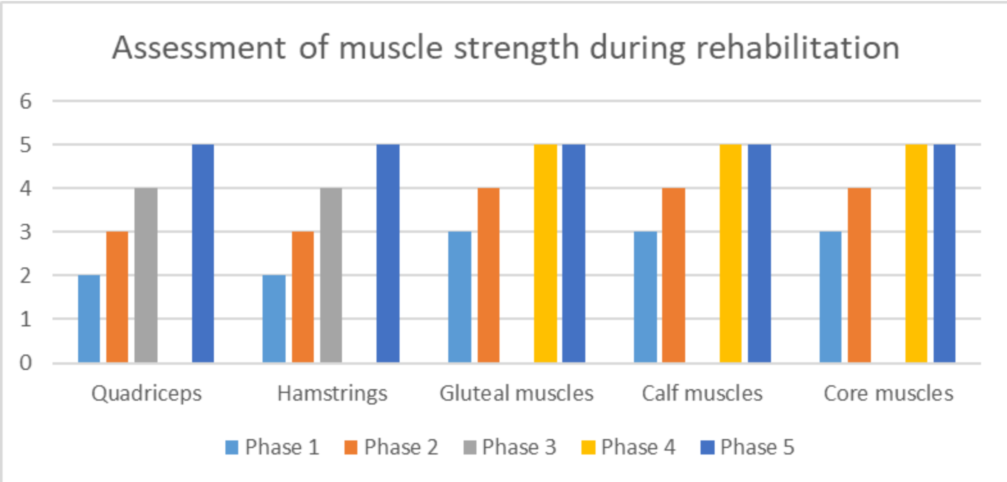

Fig. 2. *Assessment of muscle strength during rehabilitation*

The assessment of muscle strength throughout the rehabilitation process demonstrated a progressive and consistent improvement across all evaluated muscle groups. In the early phase (0–2 weeks), muscle strength was significantly reduced, particularly in the quadriceps and hamstrings, which is expected following anterior cruciate ligament injury due to pain, swelling, and neuromuscular inhibition.

These initial deficits highlight the importance of early activation strategies and controlled loading during the acute stage of rehabilitation.

During the intermediate phases (2–12 weeks), a gradual increase in muscle strength was observed, corresponding to the introduction of progressive resistance exercises and closed kinetic chain training.

The quadriceps muscle group, which is particularly susceptible to atrophy and inhibition following ACL injury, showed notable improvement; however, recovery remained slightly delayed compared to other muscle groups. This finding is consistent with existing literature, which emphasizes the challenge of restoring quadriceps strength after ACL injury.

In the advanced phases of rehabilitation (3–9 months), muscle strength values approached normal levels (4+/5 to 5/5), indicating successful restoration of muscular function. The improvement in gluteal and core muscle strength contributed significantly to overall lower limb stability and movement control.

Additionally, the restoration of hamstring strength played an important role in supporting dynamic knee stability by counteracting anterior tibial translation.

Overall, the results suggest that the structured, phase-based rehabilitation program was effective in restoring muscle strength and functional capacity. The progressive improvement observed across all muscle groups supports the importance of a comprehensive rehabilitation approach that integrates strength training, neuromuscular control, and sport-specific exercises.

Achieving near-normal muscle strength prior to return to sport is essential for reducing the risk of re-injury and ensuring optimal athletic performance.

4. Conclusions

The present study demonstrates that a structured, phase-based rehabilitation program is highly effective in restoring knee function following anterior cruciate ligament (ACL) rupture in handball players.

Progressive interventions, including pain and inflammation control, early mobilization, strength training, neuromuscular and proprioceptive exercises, and sport-specific functional drills, contributed to the recovery of muscle strength, joint stability, and range of motion.

The results indicate that early initiation of rehabilitation, combined with targeted exercises and the use of specialized equipment such as elastic bands, physiotherapy machines, TRX, and balance tools (Bosu balls), facilitates significant improvements in quadriceps and hamstring strength, neuromuscular control, and dynamic knee stability.

Full functional recovery, including restoration of range of motion and sport-specific movement patterns, was achieved within the 6–9 months period, allowing a safe return to competitive handball.

This study highlights the importance of individualized and progressive rehabilitation protocols that address both the physiological and functional demands of the athlete. Moreover, it underscores the critical role of neuromuscular training in reducing the risk of secondary ACL injuries and ensuring long-term knee health.

A comprehensive, evidence-based rehabilitation approach is essential for optimizing outcomes after ACL rupture. The findings support the implementation of structured, phase-based recovery programs in clinical and sports rehabilitation settings to maximize functional performance and facilitate a safe return to competitive sport.

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