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Multimodal Rehabilitation After Anterior Cruciate Ligament Reconstruction: Evidence from Uzbekistan, Indonesia, and Iran

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ABSTRACT

Purpose of the Study: This study aimed to compare multimodal rehabilitation approaches after anterior cruciate ligament reconstruction in Uzbekistan, Indonesia, and Iran. It examined the contribution of integrated rehabilitation interventions to improving knee function, restoring mobility, reducing postoperative complications, and supporting functional recovery across different healthcare and sports medicine contexts.

Methodology: A comparative literature review was conducted using scientific publications and rehabilitation evidence from Uzbekistan, Indonesia, and Iran between 2020 and 2025. The analysis focused on integrated rehabilitation strategies, including therapeutic exercise, neuromuscular training, electrical stimulation, cryotherapy, massage therapy, and progressive strengthening programs for postoperative ligament reconstruction recovery.

Main Findings: The findings indicated that multimodal rehabilitation consistently improved postoperative knee function, mobility, and functional performance across the three countries. Indonesian studies emphasized improvements in range of motion and edema reduction, Iranian research highlighted neuromuscular control and reinjury prevention, while Uzbek evidence demonstrated the role of therapeutic exercise and sports medicine integration. Despite differences in healthcare resources, integrated rehabilitation approaches showed comparable benefits for recovery after ligament reconstruction.

Novelty/Originality of this Study: This study presents a cross-country synthesis of multimodal rehabilitation after anterior cruciate ligament reconstruction by integrating evidence from Uzbekistan, Indonesia, and Iran. It highlights similarities and contextual differences in rehabilitation strategies across diverse healthcare systems and sports medicine practices, offering a comparative evidence base that supports adaptation of multimodal rehabilitation protocols in developing country settings.

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1. INTRODUCTION

Anterior Cruciate Ligament (ACL) injury is one of the most common musculoskeletal injuries experienced by athletes and physically active individuals worldwide [1]-[3]. ACL injuries frequently occur in sports involving rapid directional changes, pivoting, jumping, and sudden deceleration such as football, futsal,

volleyball, basketball, and wrestling [4]-[6]. The ACL plays a crucial role as the primary stabilizer of the knee joint by preventing excessive anterior translation and rotational instability of the tibia relative to the femur [7], [8], [9]. Damage to this ligament not only decreases physical performance and functional mobility but also affects psychological readiness, athletic confidence, and quality of life. Many athletes who experience ACL injuries encounter prolonged recovery periods and difficulties returning to their previous level of sports performance [10]-[12].

Globally, the incidence of ACL injuries continues to increase alongside the rapid growth of competitive and recreational sports participation [13]-[15]. This phenomenon is increasingly observed in developing countries, including Indonesia, Iran, and Uzbekistan, where sports involvement among adolescents and young adults has significantly expanded over the last decade. The increasing prevalence of ACL injuries has consequently raised the demand for effective rehabilitation systems capable of restoring knee function, reducing postoperative complications, and accelerating return-to-sport outcomes [16]-[18]. However, despite the growing need for sports rehabilitation services, healthcare infrastructure and rehabilitation capacities remain highly variable among developing countries.

Post-ACL reconstruction rehabilitation has become an essential component of successful recovery because surgical reconstruction alone is insufficient to restore optimal knee function [19]-[21]. After surgery, patients commonly experience several complications including joint stiffness, edema, quadriceps weakness, proprioceptive deficits, pain, muscle atrophy, and reduced neuromuscular control. If these conditions are not managed appropriately during the early rehabilitation phase, patients may face long-term functional limitations, recurrent injury risk, delayed return to sport, and early degenerative joint changes [22], [23]. Therefore, comprehensive rehabilitation programs are critically needed to support physiological healing and functional recovery after ACL reconstruction [24]-[26].

Modern sports medicine emphasizes that ACL rehabilitation should not rely on a single therapeutic intervention [27]-[29]. Instead, integrated multimodal rehabilitation approaches are increasingly recommended because they simultaneously address pain management, inflammation control, neuromuscular activation, joint mobility restoration, muscular strengthening, and functional movement recovery. Rehabilitation modalities such as sports injury massage, Transcutaneous Electrical Nerve Stimulation (TENS), Range of Motion (ROM) exercise therapy, cryotherapy, proprioceptive exercise, and progressive strengthening programs are widely utilized to improve rehabilitation outcomes during postoperative recovery.

In Indonesia, multimodal rehabilitation programs are increasingly implemented in specialized sports clinics such as Jogja Sports Clinic. Indonesian rehabilitation approaches generally emphasize practical and affordable therapy modalities suitable for sports clinics with limited technological resources. The rehabilitation process commonly focuses on restoring knee ROM, reducing edema, managing pain, and gradually improving functional mobility [30]-[32]. These approaches are considered highly relevant in developing-country settings where access to advanced rehabilitation technology is still limited.

Meanwhile, Iran has demonstrated substantial progress in sports medicine and orthopedic rehabilitation research. Iranian rehabilitation systems place strong emphasis on evidence-based rehabilitation, neuromuscular electrical stimulation, proprioceptive training, biomechanical assessment, and individualized rehabilitation progression. Rehabilitation protocols in Iran are often designed based on functional criteria and neuromuscular performance rather than solely time-based recovery stages. This approach contributes to more precise rehabilitation planning and improved return-to-sport readiness among athletes.

In Uzbekistan, rehabilitation research has increasingly integrated sports science, physical therapy, and exercise-based rehabilitation into postoperative orthopedic recovery programs. Rehabilitation approaches in Uzbekistan focus heavily on therapeutic exercise, muscular strengthening, restoration of movement biomechanics, and sports conditioning. Multidisciplinary collaboration between physiotherapists, sports physicians, and exercise specialists is also increasingly emphasized to optimize rehabilitation outcomes among physically active populations.

Although Indonesia, Iran, and Uzbekistan demonstrate different rehabilitation characteristics, technological capacities, and healthcare infrastructures, all three countries face similar challenges regarding postoperative edema, quadriceps weakness, joint stiffness, neuromuscular deficits, and delayed functional recovery after ACL reconstruction. These shared challenges highlight the importance of effective multimodal rehabilitation systems that can be adapted to different healthcare settings and resource capacities.

However, several important gaps remain in the current literature. Most previous studies have primarily focused on rehabilitation outcomes within single-country contexts and often evaluate isolated rehabilitation modalities rather than integrated multimodal approaches. Comparative evidence examining how different developing countries implement and optimize multimodal rehabilitation strategies after ACL reconstruction remains limited. Furthermore, studies comparing rehabilitation systems across Central Asia, Southeast Asia, and the Middle East are still rarely discussed in sports medicine literature. As a result, there is limited understanding regarding how differences in rehabilitation infrastructure, clinical resources, and therapeutic approaches influence postoperative ACL rehabilitation outcomes in developing countries.

The urgency of this study is strengthened by the increasing prevalence of ACL injuries among young athletes and physically active populations in developing countries. Effective rehabilitation systems are urgently needed not only to restore knee function but also to reduce long-term disability risk, improve athletic performance recovery, and minimize reinjury rates. In addition, understanding rehabilitation practices across different countries may provide valuable references for developing evidence-based rehabilitation systems that are adaptable, accessible, and clinically effective within diverse healthcare environments.

The novelty of this study lies in its comparative cross-country perspective integrating rehabilitation experiences and scientific developments from Uzbekistan, Indonesia, and Iran. Unlike previous studies that mainly focus on isolated rehabilitation interventions or single-country analyses, this article comparatively examines multimodal rehabilitation approaches across three developing countries representing Central Asia, Southeast Asia, and the Middle East. This integrative perspective provides broader insight into modern ACL rehabilitation practices while highlighting similarities, differences, strengths, and challenges in rehabilitation implementation across varying healthcare systems.

Therefore, this study aims to comparatively analyze rehabilitation strategies and clinical outcomes after ACL reconstruction in Uzbekistan, Indonesia, and Iran, particularly focusing on the effectiveness of multimodal rehabilitation therapy in improving range of motion (ROM), reducing edema, restoring neuromuscular function, and supporting functional recovery. This study also aims to provide evidence-based recommendations for strengthening sports rehabilitation systems in developing countries through integrated and adaptable rehabilitation approaches.

2. RESEARCH METHOD

2.1 Type of Research

This study employed a qualitative research design using a comparative literature review approach combined with evidence-based clinical analysis. The qualitative approach was selected because this study aimed to explore, compare, and interpret rehabilitation practices, clinical rehabilitation outcomes, and scientific developments related to post-Anterior Cruciate Ligament (ACL) reconstruction rehabilitation in different developing countries [33]-[35]. Rather than focusing solely on numerical statistical comparisons, this study emphasized understanding rehabilitation concepts, therapeutic strategies, and clinical rehabilitation approaches implemented in Uzbekistan, Indonesia, and Iran.

The comparative literature review method was considered appropriate because the study intended to examine similarities, differences, strengths, and limitations of multimodal rehabilitation systems across countries with varying healthcare infrastructures and sports medicine capacities. Through comparative analysis, the study sought to identify how rehabilitation modalities are applied in different clinical settings and how these approaches contribute to improving postoperative recovery outcomes after ACL reconstruction.

2.2 Data Sources

The data sources used in this study consisted of both primary clinical evidence and secondary scientific literature related to post-ACL reconstruction rehabilitation therapy. Data collection emphasized recent and relevant rehabilitation findings discussing multimodal rehabilitation approaches, postoperative functional recovery, and evidence-based sports rehabilitation systems in developing countries.

The first data source consisted of clinical rehabilitation findings obtained from Jogja Sports Clinic, Indonesia. This clinical evidence provided practical rehabilitation data regarding the implementation of multimodal rehabilitation therapy involving sports injury massage, TENS, ROM exercise therapy, cryotherapy, and progressive exercise rehabilitation among post-ACL reconstruction patients. The Indonesian clinical findings served as an important foundation for understanding rehabilitation implementation within sports clinics operating under limited technological resources while still achieving significant functional improvements.

The second data source consisted of published rehabilitation studies and sports medicine research from Iranian institutions specializing in orthopedic rehabilitation, physiotherapy, and sports science. Iranian rehabilitation literature was selected because Iran has demonstrated substantial advancement in evidence-based sports medicine and neuromuscular rehabilitation research. These studies provided information regarding individualized rehabilitation protocols, neuromuscular electrical stimulation, proprioceptive training, biomechanical assessment, and return-to-sport rehabilitation systems implemented among athletic populations.

The third data source involved rehabilitation and physical therapy studies from Uzbekistan focusing on orthopedic rehabilitation, exercise therapy, sports conditioning, and musculoskeletal recovery. Rehabilitation literature from Uzbekistan was included because the country has increasingly integrated sports science and therapeutic exercise into postoperative rehabilitation programs. Uzbek rehabilitation studies contributed valuable perspectives regarding exercise-centered rehabilitation, muscle strengthening, and restoration of biomechanical movement patterns after ACL reconstruction.

In addition to country-specific rehabilitation findings, this study also utilized international scientific literature published between 2020 and 2025 discussing modern ACL rehabilitation, multimodal therapy effectiveness, neuromuscular recovery, sports rehabilitation technology, and postoperative functional outcomes. International literature was used to strengthen theoretical understanding, support comparative analysis, and ensure that rehabilitation discussions remained aligned with recent developments in sports medicine science.

The literature included in this study consisted of:

1. Scientific journal articles discussing ACL rehabilitation.
2. Sports medicine and physiotherapy publications.
3. Orthopedic rehabilitation research papers.
4. Clinical rehabilitation reports and case studies.
5. International review articles related to multimodal rehabilitation therapy.

The selection of literature sources was conducted purposively based on several criteria, including relevance to ACL rehabilitation, discussion of multimodal therapeutic interventions, evidence-based clinical findings, and publication recency. Priority was given to literature discussing postoperative rehabilitation outcomes, ROM recovery, edema reduction, neuromuscular function restoration, and return-to-sport rehabilitation. By combining clinical findings, regional rehabilitation studies, and international scientific literature, this study aimed to produce a comprehensive comparative understanding of multimodal rehabilitation systems implemented in developing countries.

2.3 Data Collection Technique

The data collection process in this study was conducted through literature review, comparative document analysis, and evidence synthesis techniques . These techniques were chosen because the study aimed to systematically collect, examine, compare, and integrate rehabilitation findings from various scientific sources and clinical rehabilitation reports related to ACL reconstruction rehabilitation therapy. The literature review process involved identifying, selecting, and reviewing scientific publications discussing multimodal rehabilitation after ACL reconstruction [36]-[38]. The researchers examined rehabilitation literature from Uzbekistan, Indonesia, and Iran as well as international sports medicine publications discussing postoperative rehabilitation strategies, therapeutic modalities, and functional recovery outcomes.

Comparative document analysis was then conducted to identify similarities and differences among rehabilitation systems implemented in the three countries [39]-[41]. The comparison focused on rehabilitation modalities, rehabilitation progression, clinical objectives, rehabilitation duration, therapeutic effectiveness, and functional recovery outcomes. This comparative process enabled the researchers to understand how each country adapts rehabilitation strategies according to its healthcare infrastructure, technological capacity, and sports medicine development. The data collection process also involved evidence synthesis to integrate rehabilitation findings from different studies into broader thematic categories. Rehabilitation outcomes from various publications were grouped and analyzed based on their contribution to postoperative ACL recovery. The synthesis process aimed to identify rehabilitation interventions consistently associated with positive clinical outcomes across different healthcare settings.

Several major rehabilitation outcome indicators were used as the focus of data collection, including:

1. Knee Range of Motion (ROM) improvement following rehabilitation intervention.
2. Reduction of postoperative edema and inflammation.
3. Neuromuscular recovery and quadriceps activation improvement.
4. Pain management effectiveness during rehabilitation phases.
5. Restoration of functional movement and mobility.
6. Improvement of proprioception and dynamic knee stability.
7. Return-to-sport readiness and functional athletic recovery.

Furthermore, the data collection process emphasized identifying multimodal rehabilitation approaches combining several therapeutic modalities simultaneously. This focus was important because integrated rehabilitation systems are increasingly recognized as more effective than single-modality interventions in managing complex postoperative impairments after ACL reconstruction.

2.4 Data Analysis Technique

The data collected in this study were analyzed using comparative thematic analysis. This analytical approach was selected because the study aimed to compare rehabilitation systems, identify recurring rehabilitation themes, and synthesize evidence-based rehabilitation strategies from different countries. Comparative thematic analysis enabled the researchers to systematically organize rehabilitation findings while identifying patterns, similarities, differences, strengths, and limitations across rehabilitation approaches implemented in Uzbekistan, Indonesia, and Iran. The first stage of analysis involved organizing rehabilitation findings into thematic categories based on rehabilitation components and clinical rehabilitation objectives. Each rehabilitation study and clinical

report was carefully reviewed to identify therapeutic modalities, rehabilitation progression strategies, and postoperative recovery outcomes discussed in the literature.

The rehabilitation approaches from each country were then categorized based on several analytical indicators, including:

1. Rehabilitation modalities utilized during postoperative recovery.
2. Clinical rehabilitation objectives targeted in each rehabilitation phase.
3. Rehabilitation duration and progression systems.
4. Functional outcomes achieved after rehabilitation.
5. Neuromuscular recovery approaches and strengthening programs.
6. Pain and edema management strategies.
7. Return-to-sport rehabilitation procedures.
8. Strengths and limitations of rehabilitation systems.

After thematic categorization, cross-country comparisons were conducted to identify similarities and differences among rehabilitation systems. The comparative analysis specifically examined how each country implemented multimodal rehabilitation approaches and how rehabilitation infrastructures influenced rehabilitation effectiveness and clinical outcomes. The analysis also evaluated the integration of therapeutic modalities such as massage therapy, TENS, ROM exercise therapy, cryotherapy, proprioceptive training, strengthening exercises, and neuromuscular rehabilitation. Particular attention was given to rehabilitation modalities consistently associated with positive outcomes such as improved ROM, edema reduction, enhanced muscular activation, and restoration of functional movement.

In addition, the analysis explored broader contextual factors influencing rehabilitation implementation in developing countries, including accessibility of rehabilitation facilities, technological resources, multidisciplinary collaboration, sports medicine development, and rehabilitation service sustainability. This contextual analysis was important to understand the practical challenges faced by rehabilitation systems in resource-limited settings. The final stage of analysis involved synthesizing all rehabilitation findings into integrated conclusions regarding effective evidence-based rehabilitation strategies applicable to developing countries. Through this synthesis process, the study aimed to formulate broader recommendations for improving postoperative ACL rehabilitation systems while emphasizing adaptable, accessible, and clinically effective multimodal rehabilitation approaches. Overall, the comparative thematic analysis enabled this study to provide a comprehensive understanding of ACL rehabilitation practices across different developing countries while highlighting important opportunities for future sports rehabilitation development and international clinical collaboration.

3. RESULTS AND DISCUSSION

3.1 Rehabilitation Practices in Indonesia

The rehabilitation approach after Anterior Cruciate Ligament (ACL) reconstruction in Indonesia has increasingly developed alongside the growth of sports medicine services and the rising number of sports-related knee injuries among physically active populations. Rehabilitation programs in Indonesia generally emphasize practical, affordable, and multimodal therapeutic interventions that can be implemented effectively within sports clinics and rehabilitation centers with moderate healthcare infrastructure. This approach is considered highly relevant in the Indonesian context because many rehabilitation facilities still face limitations regarding advanced rehabilitation technology, specialized equipment, and accessibility for patients living outside major urban areas.

One of the important characteristics of the Indonesian rehabilitation system is its emphasis on integrated multimodal rehabilitation therapy during the early postoperative phase. Clinical evidence from Jogja Sports Clinic demonstrated that combining sports injury massage, Transcutaneous Electrical Nerve Stimulation (TENS), Range of Motion (ROM) exercise therapy, and cryotherapy produced significant improvements in both active and passive knee ROM while simultaneously reducing postoperative edema among post-ACL reconstruction patients. These findings indicate that combining multiple therapeutic modalities may provide synergistic physiological effects capable of accelerating recovery more effectively than isolated rehabilitation interventions.

In Indonesia, rehabilitation programs commonly focus on progressive functional recovery rather than solely symptom reduction. The rehabilitation process aims not only to decrease pain and swelling but also to gradually restore joint mobility, muscular activation, neuromuscular control, and functional movement patterns required for daily activities and sports participation. This functional rehabilitation perspective is increasingly recognized as essential because postoperative ACL patients often experience complex impairments involving muscular weakness, proprioceptive deficits, joint stiffness, and movement asymmetry.

Sports injury massage remains one of the most commonly utilized rehabilitation modalities in Indonesian sports rehabilitation clinics. Massage techniques such as friction massage, effleurage, and soft tissue mobilization are frequently applied to improve local blood circulation, reduce muscle tension, facilitate lymphatic drainage, and minimize postoperative edema accumulation around the knee joint. Massage therapy is also believed to contribute

to soft tissue relaxation and scar tissue mobilization, which may help improve joint flexibility and reduce postoperative stiffness during the early rehabilitation phase.

Another widely utilized rehabilitation modality in Indonesia is TENS therapy. TENS is commonly applied to reduce postoperative pain through electrical stimulation mechanisms that modulate pain signal transmission within the nervous system. Pain reduction is considered critically important because excessive postoperative pain often limits patient participation during exercise therapy sessions. In addition to pain modulation, TENS is also utilized to support neuromuscular activation and improve muscle recruitment, particularly among patients experiencing quadriceps inhibition after ACL reconstruction surgery.

Cryotherapy or cold therapy also plays a major role in Indonesian rehabilitation programs. Ice compresses and cold application techniques are commonly administered after rehabilitation exercises to reduce inflammation, minimize edema formation, and decrease pain sensation. Cryotherapy is considered highly practical and affordable because it can be easily continued independently by patients at home. This home-based continuation of rehabilitation is particularly important in Indonesia, where rehabilitation accessibility and transportation barriers may limit the frequency of direct clinical visits for some patients.

Range of Motion (ROM) exercise therapy constitutes another essential component of Indonesian ACL rehabilitation protocols. ROM exercise programs generally include heel slides, quadriceps isometric exercises, hamstring strengthening exercises, prone hangs, straight leg raises, and patellar mobilization exercises. These interventions aim to progressively restore knee flexibility, prevent joint contracture, improve muscular activation, and support the restoration of normal gait patterns. ROM exercises are usually introduced gradually according to postoperative healing stages and patient tolerance levels to avoid excessive joint stress during the early recovery phase.

Patellar mobilization exercises are also frequently emphasized in Indonesian rehabilitation systems because restricted patellar mobility is often associated with postoperative stiffness and reduced knee flexion. Through manual mobilization techniques, therapists attempt to restore normal patellar movement and improve joint mechanics during flexion and extension movements. This intervention contributes significantly to restoring functional knee movement during walking, squatting, and sports-related activities.

Another important aspect of rehabilitation practice in Indonesia is the strong emphasis on patient compliance and rehabilitation continuity. Since rehabilitation outcomes after ACL reconstruction are highly dependent on long-term exercise adherence, therapists commonly provide home-based rehabilitation instructions and patient education regarding self-management strategies. Patients are encouraged to continue stretching, strengthening, and cryotherapy exercises independently outside clinical sessions to maintain rehabilitation progress and reduce the risk of functional decline.

Although access to sophisticated rehabilitation technologies remains limited in many Indonesian rehabilitation centers, evidence demonstrates that systematic and consistently implemented multimodal rehabilitation programs can still produce significant clinical improvements. This finding highlights that effective rehabilitation does not always depend on expensive technology but rather on structured rehabilitation planning, therapist competence, patient compliance, and appropriate integration of therapeutic modalities.

Furthermore, the Indonesian rehabilitation model reflects the importance of adaptive rehabilitation systems suitable for developing countries. The ability to combine affordable therapeutic modalities with functional rehabilitation principles provides an important example of how sports rehabilitation services can remain effective despite limited healthcare resources. Consequently, the Indonesian rehabilitation experience offers valuable insight for other developing countries facing similar challenges in sports medicine infrastructure and rehabilitation accessibility.

3.2 Rehabilitation Practices in Iran

Iran has emerged as one of the leading countries in sports medicine and orthopedic rehabilitation research within the Middle East. The development of sports rehabilitation systems in Iran has been strongly influenced by advances in evidence-based sports medicine, biomechanics, physiotherapy science, and athletic performance rehabilitation. Iranian rehabilitation approaches after ACL reconstruction are generally characterized by the integration of scientific assessment methods, individualized rehabilitation progression, and technologically supported neuromuscular rehabilitation strategies.

One of the primary focuses of Iranian rehabilitation research is the restoration of neuromuscular function after ACL reconstruction. Iranian researchers consistently identify quadriceps weakness, neuromuscular inhibition, proprioceptive deficits, and biomechanical asymmetry as major barriers preventing successful return-to-sport outcomes after surgery. As a result, rehabilitation programs in Iran commonly emphasize progressive strengthening exercises combined with neuromuscular re-education interventions aimed at restoring lower limb stability and dynamic movement control.

Neuromuscular Electrical Stimulation (NMES) is one of the most frequently utilized rehabilitation modalities within Iranian sports rehabilitation programs. NMES is applied to stimulate muscular contraction and facilitate quadriceps activation during the early postoperative period when voluntary muscle contraction remains

limited due to pain, swelling, and arthrogenic muscle inhibition. Iranian rehabilitation studies suggest that combining NMES with strengthening exercises may significantly improve muscle activation and accelerate muscular recovery compared to exercise therapy alone.

In addition to NMES, Iranian rehabilitation systems strongly emphasize balance and proprioceptive training. Proprioceptive deficits after ACL reconstruction are recognized as important contributors to knee instability and recurrent injury risk. Therefore, Iranian rehabilitation protocols commonly incorporate balance board exercises, single-leg stability training, dynamic postural control exercises, and neuromuscular coordination drills to improve joint awareness and lower extremity stability.

Closed kinetic chain exercises are also widely implemented in Iranian rehabilitation programs because these exercises are considered safer and more functional during the postoperative rehabilitation phase. Closed kinetic chain exercises such as mini squats, step-ups, lunges, and controlled weight-bearing activities help improve muscular strength, joint stability, and movement coordination while minimizing excessive strain on the reconstructed ligament. These exercises are gradually progressed according to patient functional capacity and healing status.

Another important component of Iranian rehabilitation practice is functional movement retraining. Rehabilitation specialists in Iran place strong emphasis on restoring biomechanically correct movement patterns before patients are allowed to return to sports participation. Functional retraining commonly includes gait correction, jumping mechanics, landing control exercises, pivoting drills, and sport-specific agility training. This approach aims to reduce biomechanical asymmetry and prevent reinjury after rehabilitation completion.

Iranian rehabilitation systems are also highly recognized for emphasizing individualized rehabilitation progression. Unlike traditional time-based rehabilitation approaches, many Iranian rehabilitation programs utilize functional criteria-based progression systems. Patients are required to achieve specific benchmarks related to muscular strength, balance, joint stability, ROM, and neuromuscular control before advancing to the next rehabilitation phase. This individualized progression approach allows rehabilitation programs to be adjusted according to each patient's recovery capacity and functional readiness.

Technological advancement also represents a major strength of Iranian rehabilitation systems. Several rehabilitation centers and sports medicine institutions in Iran increasingly utilize advanced rehabilitation technologies such as force plate analysis, wearable motion sensors, motion capture systems, electromyography (EMG), and biomechanical gait analysis. These technologies help therapists identify movement asymmetries, muscular deficits, and biomechanical abnormalities more accurately during rehabilitation assessment.

The use of advanced assessment technology contributes significantly to rehabilitation precision and injury prevention strategies. Through biomechanical monitoring, therapists can detect abnormal movement patterns that may increase reinjury risk after return to sports participation. This evidence-based assessment system enables more accurate rehabilitation adjustments and supports safer return-to-sport decision making.

Another important characteristic of Iranian rehabilitation practice is the close integration between sports medicine physicians, physiotherapists, exercise specialists, and athletic trainers. Multidisciplinary collaboration is considered essential because ACL rehabilitation involves not only orthopedic recovery but also functional performance restoration, psychological readiness, and long-term injury prevention.

Overall, Iran demonstrates how developing countries can successfully integrate scientific research, technological innovation, and evidence-based rehabilitation principles into modern sports rehabilitation systems. The Iranian experience highlights the importance of individualized rehabilitation progression, neuromuscular rehabilitation, and biomechanical assessment in optimizing postoperative ACL recovery and return-to-sport outcomes.

3.3 Rehabilitation Practices in Uzbekistan

The development of sports rehabilitation systems in Uzbekistan has increasingly reflected the integration of sports science, physical education, orthopedic rehabilitation, and exercise therapy into postoperative musculoskeletal recovery programs. As sports participation continues to grow among young athletes and physically active populations, rehabilitation services in Uzbekistan have become more focused on restoring functional movement, athletic performance, and long-term musculoskeletal health following sports injuries such as ACL rupture.

Uzbek rehabilitation approaches after ACL reconstruction primarily emphasize exercise-centered rehabilitation strategies. Therapeutic exercise is considered the core component of rehabilitation because it directly contributes to muscular strengthening, joint stabilization, neuromuscular adaptation, and restoration of biomechanical movement patterns. Rehabilitation specialists in Uzbekistan commonly prioritize progressive exercise therapy to ensure that postoperative recovery progresses systematically from basic mobility restoration to advanced functional performance rehabilitation.

One of the major strengths of the Uzbek rehabilitation system is its strong focus on muscle strengthening and lower limb symmetry restoration. Rehabilitation programs frequently include quadriceps strengthening, hamstring strengthening, calf strengthening, hip stabilization exercises, and core muscle activation programs.

These interventions aim to restore balanced muscular function between the injured and non-injured limbs while improving dynamic knee stability during movement.

Functional mobility training also constitutes an essential component of rehabilitation practice in Uzbekistan. Patients commonly undergo progressive gait training, weight-bearing exercises, balance exercises, stair-climbing drills, and controlled movement retraining to restore normal movement mechanics after surgery. These interventions are particularly important because postoperative movement compensation patterns may persist if not corrected during rehabilitation.

Manual therapy techniques are also integrated into many Uzbek rehabilitation programs. Therapists frequently utilize joint mobilization, soft tissue mobilization, stretching therapy, and flexibility exercises to reduce joint stiffness, improve tissue elasticity, and restore ROM. Manual therapy is commonly combined with exercise therapy to optimize joint movement and reduce postoperative functional limitations.

Sports conditioning exercises are another important feature of rehabilitation practice in Uzbekistan. Rehabilitation specialists often integrate conditioning programs designed to restore endurance, agility, coordination, and sport-specific performance before athletes return to full participation. These programs are particularly relevant for athletes involved in wrestling, football, martial arts, athletics, and other sports requiring high levels of lower extremity stability and explosive movement.

The rehabilitation philosophy in Uzbekistan is strongly influenced by sports performance restoration. Rather than focusing solely on symptom reduction, rehabilitation specialists aim to restore overall athletic readiness and movement efficiency. This approach reflects the understanding that successful ACL rehabilitation must prepare athletes not only for daily activities but also for the physical demands of competitive sports participation.

Compared to Iran, rehabilitation systems in Uzbekistan generally utilize fewer advanced technological assessment tools. However, rehabilitation effectiveness remains highly dependent on structured exercise progression, therapist supervision, and consistent rehabilitation participation. This demonstrates that exercise-based rehabilitation remains highly effective even in settings where technological resources are more limited.

Multidisciplinary collaboration is also increasingly emphasized within Uzbek rehabilitation systems. Sports physicians, physiotherapists, rehabilitation specialists, and exercise scientists commonly work together to develop rehabilitation programs tailored to patient functional needs and sports participation goals. This collaborative approach supports more comprehensive rehabilitation planning and improves long-term functional outcomes.

Another important aspect of rehabilitation practice in Uzbekistan is the emphasis on gradual return-to-sport preparation. Athletes are generally required to demonstrate adequate muscular endurance, dynamic stability, movement control, and functional performance before being cleared for sports participation. This progression-based rehabilitation strategy aims to reduce reinjury risk and ensure safer athletic reintegration.

Overall, the Uzbek rehabilitation approach demonstrates that structured exercise-centered rehabilitation programs can produce significant postoperative functional improvements despite limited access to sophisticated rehabilitation technology. The Uzbek experience highlights the importance of therapeutic exercise, sports conditioning, and movement restoration in supporting successful ACL rehabilitation within developing-country settings.

3.4 Comparative Analysis Between Uzbekistan, Indonesia, and Iran

Comparative analysis between rehabilitation practices in Uzbekistan, Indonesia, and Iran revealed several important similarities and differences regarding rehabilitation philosophy, therapeutic priorities, technological integration, and clinical rehabilitation strategies after ACL reconstruction.

One of the most significant similarities among the three countries is the shared emphasis on multimodal rehabilitation approaches. All rehabilitation systems recognize that postoperative ACL recovery requires integrated therapeutic interventions addressing multiple physiological and functional impairments simultaneously. Consequently, rehabilitation programs in all three countries focus on progressive ROM restoration, edema reduction, pain management, muscular strengthening, neuromuscular recovery, and functional movement restoration.

Another important similarity involves the recognition of exercise therapy as the central component of postoperative rehabilitation. Despite differences in rehabilitation infrastructure and technological resources, all three countries prioritize progressive therapeutic exercise as the primary strategy for restoring knee function, muscular strength, and movement stability after ACL reconstruction.

However, each country demonstrates distinct rehabilitation priorities and unique strengths. Indonesia primarily emphasizes practical and affordable multimodal rehabilitation suitable for sports clinics operating within moderate healthcare infrastructure. Indonesian rehabilitation systems focus heavily on combining massage therapy, TENS, ROM exercises, and cryotherapy to achieve progressive functional recovery while maintaining rehabilitation accessibility and affordability.

Iran, on the other hand, demonstrates stronger integration of evidence-based sports medicine, biomechanical assessment, and technologically supported rehabilitation systems. Iranian rehabilitation programs

place significant emphasis on neuromuscular rehabilitation, individualized progression systems, biomechanical analysis, and advanced rehabilitation technology such as force plate assessment and motion analysis systems. This approach contributes to highly individualized rehabilitation planning and more precise return-to-sport assessment.

Meanwhile, Uzbekistan demonstrates a rehabilitation philosophy strongly centered on therapeutic exercise, sports conditioning, and athletic performance restoration. Uzbek rehabilitation systems emphasize restoring lower limb symmetry, muscular endurance, and biomechanical movement efficiency through progressive exercise-centered rehabilitation programs. Although technological resources may be more limited, rehabilitation effectiveness is maintained through structured rehabilitation progression and strong exercise-based therapeutic strategies.

From a clinical perspective, all three rehabilitation systems demonstrated that multimodal rehabilitation programs significantly contribute to improved postoperative outcomes. Common rehabilitation benefits identified across the three countries included:

1. Improvement of active and passive knee ROM.
2. Reduction of postoperative edema and inflammation.
3. Enhancement of muscular activation and strength.
4. Improvement of functional mobility and gait mechanics.
5. Restoration of neuromuscular control and proprioception.
6. Increased readiness for return-to-sport participation.

The comparative findings further support the growing international consensus that integrated rehabilitation approaches are substantially more effective than isolated therapeutic modalities after ACL reconstruction. Combining exercise therapy, pain management, neuromuscular rehabilitation, edema control, and functional movement retraining appears to provide synergistic physiological and functional benefits capable of accelerating postoperative recovery.

Another important finding from the comparative analysis is that rehabilitation effectiveness is not determined solely by technological sophistication. While Iran demonstrates greater integration of advanced rehabilitation technology, Indonesia and Uzbekistan also achieve meaningful rehabilitation outcomes through structured, affordable, and exercise-centered rehabilitation systems. This suggests that rehabilitation quality depends not only on equipment availability but also on rehabilitation planning, therapist expertise, patient adherence, and consistency of therapeutic intervention.

Overall, the comparative analysis highlights that developing countries can successfully implement effective ACL rehabilitation systems through adaptive and evidence-based rehabilitation strategies tailored to local healthcare capacities and rehabilitation resources.

3.5 Clinical Implications for Developing Countries

The comparative findings from Uzbekistan, Indonesia, and Iran provide several important clinical implications for the development of sports rehabilitation systems in developing countries. One of the most important implications is that effective ACL rehabilitation does not always require highly sophisticated or expensive rehabilitation technology. Structured multimodal rehabilitation programs utilizing affordable therapeutic modalities can still produce significant clinical improvements when implemented systematically and consistently.

This finding is highly relevant for developing countries where healthcare infrastructure, rehabilitation accessibility, and technological resources often remain limited. Rehabilitation systems that combine exercise therapy, pain management, neuromuscular activation, ROM restoration, and edema control may provide effective postoperative recovery even in resource-constrained settings. Therefore, rehabilitation planning and therapeutic integration may be more important than technological complexity alone.

The study also highlights the importance of implementing integrated rehabilitation systems rather than isolated treatment approaches. ACL reconstruction affects multiple physiological systems simultaneously, including joint mobility, muscular function, proprioception, neuromuscular coordination, and psychological readiness. Consequently, rehabilitation interventions should address these impairments comprehensively through multimodal therapeutic strategies.

Another important implication involves the need for individualized rehabilitation progression based on functional recovery rather than solely postoperative timelines. Evidence from Iran particularly demonstrates that rehabilitation progression guided by muscular strength, balance, stability, and functional performance assessment may contribute to safer and more effective return-to-sport outcomes. Developing countries may benefit from gradually adopting more function-based rehabilitation progression systems to improve rehabilitation precision and reduce reinjury risk.

The findings also emphasize the importance of patient education and rehabilitation adherence. Since rehabilitation success after ACL reconstruction heavily depends on long-term participation and exercise consistency, rehabilitation programs should encourage home-based exercise continuation, self-management strategies, and active patient involvement throughout the recovery process.

Furthermore, multidisciplinary collaboration between sports physicians, physiotherapists, exercise specialists, rehabilitation therapists, and athletic trainers should be strengthened within developing-country rehabilitation systems. Collaborative rehabilitation planning allows for more comprehensive patient management and may improve both short-term recovery and long-term functional outcomes.

International collaboration among developing countries in sports medicine and rehabilitation research also represents an important opportunity for future rehabilitation advancement. Comparative rehabilitation research, knowledge exchange, and clinical collaboration may accelerate the development of evidence-based rehabilitation systems adapted to regional healthcare capacities and athlete needs.

Finally, the findings of this study indicate that future sports rehabilitation development in developing countries should prioritize rehabilitation accessibility, therapist training, evidence-based clinical practice, and adaptable multimodal rehabilitation systems. Strengthening these aspects may significantly improve postoperative recovery outcomes, reduce long-term disability risk, and support safer return-to-sport participation among athletes and physically active populations.

4. CONCLUSION

Multimodal rehabilitation therapy after ACL reconstruction has demonstrated significant effectiveness in improving knee ROM, reducing edema, restoring neuromuscular function, and enhancing functional recovery in Uzbekistan, Indonesia, and Iran. Although each country applies different rehabilitation strategies according to available infrastructure and sports medicine development, all rehabilitation systems emphasize integrated therapeutic approaches combining exercise therapy, pain management, and progressive functional rehabilitation. Indonesia highlights practical and affordable multimodal rehabilitation suitable for developing sports clinics. Iran demonstrates advanced evidence-based rehabilitation emphasizing neuromuscular training and individualized progression systems. Uzbekistan emphasizes exercise-centered rehabilitation integrated with sports performance restoration. Overall, the comparative findings confirm that multimodal rehabilitation remains the most effective strategy for early-phase ACL reconstruction recovery in developing countries. Future rehabilitation development should prioritize individualized protocols, multidisciplinary collaboration, technological adaptation, and evidence-based rehabilitation systems to optimize long-term clinical and athletic outcomes.

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AUTHOR CONTRIBUTIONS

Conceptualization, K.D. and R.S.; Methodology, K.D., R.S., M.S., and M.M.; Literature Search and Data Collection, K.D. and M.S.; Data Curation, K.D. and R.S.; Formal Analysis, K.D. and M.M.; Interpretation of Evidence, R.S., M.S., and M.M.; Writing – Original Draft Preparation, K.D. and R.S.; Writing – Review & Editing, M.S. and M.M.; Visualization, K.D.; Supervision, R.S.; Project Administration, K.D. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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