تأثير العلاج المائي على إعادة تأهيل الرباط الصليبي الأمامي بعد الجراحة

م.م.كاروان أحمد كريم
جامعة كرميان / كلية التربية
الاساس / قسم التربية البدنية
وعلوم الرياضة
Karwan.Ahmed@gmail.com

م.م.رنجبر إسماعيل رمضان
جامعة كرميان / كلية التربية
الاساس / قسم التربية البدنية
وعلوم الرياضة
Ranjber.Ismail@gmail.com

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The Effect of Hydrotherapy on Anterior Cruciate Ligament (ACL) Post-Surgery Rehabilitation

Assistant. Teacher Karwan Ahmed Karim
University of Garmian / College of Basic Education / Department of Physical Education & Sport Science

Assistant. Teacher. Ranjber Ismail Ramadhan
University of Garmian / College of Basic Education / Department of Physical Education & Sport Science

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ملخص

تتناول هذه الورقة البحثية ثلاث حالات سريرية مختلفة تتضمن استخدام العلاج المائي (المعروف أيضًا بالعلاج المائي) كجزء من العلاج غير الجراحي للأفراد المصابين بتمزق الرباط الصليبي الأمامي (ACL) بدرجات متفاوتة في هذه الحالة)، حيث تُسلط الضوء على مدى فعالية هذه الطريقة في إعادة التأهيل التحفظي لهؤلاء الأفراد. تراوحت أعمار المشاركين الثلاثة في هذه الدراسة بين 18 و22 عامًا، وقد عانى كل منهم من درجة مختلفة من تمزق الرباط الصليبي الأمامي، بدءًا من التواء من الدرجة الأولى أو الثانية وصولًا إلى تمزق كامل. تراوحت مدة خضوعهم لإعادة التأهيل بين 3 و8 أشهر (للمشاركين ذوي الإصابة المتوسطة والشديدة على

التوالي)، وتراوح عدد جلسات إعادة التأهيل الموصوفة بين 12 و35 جلسة (للمشاركين نفسيهما على التوالي).

على الرغم من اختلاف درجات الإصابة، فقد تعافى جميع المشاركين الثلاثة بشكل ممتاز، وتم السماح لهم بالعودة إلى مستوى أدائهم الرياضي السابق (الطبيعي أو التنافسي). في كل مرحلة من مراحل إعادة التأهيل لكل مشارك، استُخدم العلاج المائي كأحد الأساليب العلاجية، سواءً في المراحل المبكرة للسيطرة على الألم والتورم، أو لاحقًا في التدريب العصبي العضلي والتدريب البليومتري. ويمكن اعتبار البروتوكولات المختلفة الواردة هنا دليلًا مفيدًا قائمًا على الأدلة عند تطبيق العلاج التحفظي للأفراد المصابين بتمزق الرباط الصليبي الأمامي.

Abstract

The research paper at hand discusses three different clinical scenarios involving the use of aquatic therapy (the same thing as hydrotherapy) as part of non-surgical treatment for individuals with an Anterior Cruciate Ligament (ACL) injury (in this instance with varying degrees) in that it provides insight into how effective this method was as it pertains to conservative rehabilitation of individuals with an ACL injury. The three participants in this study were all in the 18 to 22 year age range, and each of them experienced a different degree of an ACL injury from a Grade I/II ACL sprain to a significant/total rupture. The length of time that they were involved in rehabilitation ranged from 3 to 8 months (for the moderate and severe participants respectively) and the number of prescribed rehabilitation sessions ranged from 12 to 35 sessions (for the same two participants respectively).

Despite their varying degrees of injury, all three participants made an excellent recovery, and were cleared for return to their previous level of athletic performance (normal or competitive). At every stage of rehabilitation in each participant's process, hydrotherapy was a modality utilized throughout, whether it was during the early stages of pain and swelling control, or later on in neuromuscular and plyometric training. The various protocols provided herein can be considered a useful, evidence based guide when conducting conservative treatment for individuals with ACL injuries.

Problem Statement

In all types of sports and for all populations, anterior cruciate ligament (ACL) injuries have one of greatest impacts to function and overall physical activity. Because the ACL is the major ligament that provides

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stability in the knee joint through resisting anterior dislocation of the tibia and resisting rotational forces when subjected to dynamic loading, it sustains a high degree of injury from contact, deceleration, and twisting movements. Consequently, ACL injuries produce considerable levels of pain, instability, muscle inhibition, and decreased quality of life and sports participation.

Even with progressions in surgical techniques used to reconstruct ACLs, a large number of ACL injuries (i.e. incomplete tears and sprains) can be treated non-surgically through conservative rehabilitation management. Nonetheless, non-surgical conservative rehabilitation presents its own unique clinical challenges: early stages of rehabilitation are limited due to pain and swelling; land-based traditional loading can exceed the tissue tolerance during the healing process; and it is necessary to systematically treat the progressive strength and neuromuscular deficits of the involved limb prior to returning to sport safely.

A major clinical challenge associated with ACL rehabilitation is an inability to start early, progressive exercise safely and without pain. Hydrotherapy helps solve this problem by utilizing the physical properties of water, including buoyancy, hydrostatic pressure, viscosity, and thermodynamics, to allow patients to perform movements and train their body under loading or cardiovascularly at intensities they may not be able to do or do safely on land (Tovin et al., 1994; Villalta & Peiris, 2013; Buckthorpe et al., 2019). Despite the popularity of hydrotherapy in rehabilitation centres and with patients, there is a lack of literature documenting formal, phase-oriented hydrotherapy protocols within fully multimodally rehabilitated patients at varying levels of injuries.

This report provides ground-breaking evidence for clinicians by detailing how hydrotherapy can play an important role in rehabilitating three actual patients with varying degrees of ACL injuries through a multi-faceted/rehabilitation approach. Comprehensive step-by-step protocols are provided with clinical rationale and measurable outcomes for each patient case, giving clinicians a practical, evidence-based guide for using hydrotherapy as part of their ACL rehabilitation program.

Study Overview & Introduction

This is a report discussing how 3 different patients with Anterior Cruciate Ligament (ACL) injuries were rehabilitated. Each patient's rehabilitation program included physiotherapy modalities, hydrotherapy (i.e., aquatic therapy) and fitness training as part of their overall rehabilitation. The

level of injury severity and number of sessions each patient completed varies, along with the length of time in rehabilitation, thus providing a useful source for comparison of different treatment options.

The ACL is the main stabilizing ligament in the knee and provides stability by resisting anterior tibial translation and rotational forces. The degree of injury may vary from partial micro-tears (Grade I/II sprains) to complete tears (Grade III), with different management options ranging from conservative physiotherapy treatment through to surgical reconstruction. Each of the patients in this study were treated conservatively utilizing electrotherapy, hydrotherapy and progressive exercise rehabilitation, as opposed to surgery.

Each participant's hydrotherapy and fitness protocols are provided in step-by-step format as reference materials for research purposes as well as for clinical purposes. Each exercise is described with its dosage, technique instructions and rationale for performance.

CASE 1 — Ahmad Aziz Muhammad

Anterior Cruciate Ligament Sprain | Conservative Management

Patient Profile

Full Name	Ahmad Aziz Muhammad
Age	18 years
Diagnosis	Anterior Cruciate Ligament (ACL) Sprain
Sessions Completed	12 Sessions
Rehabilitation Duration	3 Months
Outcome	Full recovery — returned to normal activity
Management Type	Conservative (Non-surgical)

Modalities Used

□TENS(Transcutaneous Electrical Nerve Stimulation)	**□Ultrasound Therapy(1–3 MHz Therapeutic)**	**□Hydrotherapy(Aquatic Exercise Pool)**

Clinical Rationale

At the age of 18, Ahmad has an incomplete ligament tear (a sprain) which is an ideal candidate for conservative rehabilitation. An incomplete ligament injury combined with the growth plate of a young person provide for the best chance of successful non-operative management when a patient complies with their treatment plan.

Transcutaneous electrical nerve stimulation (TENS) was used during the initial treatments to assist in the management of acute pain using the gate control mechanisms (Fitzgerald et al., 2003). TENS reduced Ahmad's reliance on orally administered analgesics and allowed for earlier participation in his active rehabilitation program. Ultrasound applied at Therapeutic frequencies promotes tissue healing through thermal and non-thermal (through cavitation and streaming) effects. This promotes collagen synthesis and reduces inflammation at the ligament level (Amaral et al., 2022).

Hydrotherapy was begun at session 3 to allow for early mobilization of Ahmad's knee joint without pain. Achieving mobility on land would have been too painful. The 12 treatment sessions over 3 months provided progressive loading of the healing ligament within the appropriate timeframe for tissue repair.

OUTCOME

Complete recovery achieved in 12 sessions over 3 months. At discharge, Ahmad demonstrated full range of motion, symmetrical lower limb strength, and no pain or instability on functional testing.

Phase Rehabilitation Timeline

Phase	Duration	Goal	Key Exercises
Phase 1	Weeks 1–3(4 sessions)	Pain control & edema reduction	TENS, therapeutic ultrasound, gentle ROM exercises in water, heel slides
Phase 2	Weeks 4–8(5 sessions)	Strength restoration	Aquatic squats, pool walking, leg press, hip strengthening, quad/hamstring sets
Phase 3	Weeks 9–	Return to	Pool running, proprioception

Phase	Duration	Goal	Key Exercises
	12(3 sessions)	function	drills, sport-specific agility, full weight-bearing strength exercises

CASE 2 — Peshawar Lukman

Partial ACL Tear | Extended Conservative Rehabilitation

Patient Profile

Full Name	Peshawar Lukman
Age	22 years
Diagnosis	Partial Tear of the Anterior Cruciate Ligament
Sessions Completed	20 Sessions
Rehabilitation Duration	6 Months
Outcome	Full recovery — returned to sport activity
Management Type	Conservative (Non-surgical)

Modalities Used

□**TECAR Therapy(Capacitive/Resistive Energy Transfer)**	□**TENS(Electrical Stimulation)**	□**Infrared Therapy(Near-Infrared Light)**	□**Hydrotherapy(Aquatic Pool)**	□**Fitness Training(Progressive Land Gym)**

Clinical Rationale

Peshawar's injury was classified as a partial tear of the anterior cruciate ligament (ACL), which is a more severe injury than Ahmad's sprain. Because it is a partial tear, his rehabilitation program will take longer in duration than Ahmad's due to the time required for healing of the ligament. Peshawar's injury will take longer to rehabilitate due to the longer rehabilitation time involved with a partial tear than with an ACL sprain. The collagen fibers of a ligament may or may not be disrupted

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when an injured ligament undergoes a type of injury (such as a sprain, partial tear, or complete tear). Conservative treatment can provide excellent functional outcomes for individuals who are young and motivated enough to engage in the rehabilitation process, when insufficient collagen fibers exist to stabilize the joint after a partial tear occurs.

TECAR (Capacitive and Resistive Energy Transfer) therapy was selected as the primary physiotherapy treatment modality because it has a significantly greater penetration depth than traditional ultrasound. TECAR is able to achieve deep tissue hyperthermia that will accelerate cellular metabolism, promote neovascularisation and enhance collagen remodelling within the partially torn ACL (Haghighat et al., 2022; Frontera et al., 2024). This process is critical to facilitate tissue repair over a 6-month rehabilitation period.

Infrared therapy was used in conjunction with TECAR as an adjunct therapy to address pain and to improve circulation in the joint capsule at the surface level. The total number of treatment modalities will be greater than what was expected because of the greater severity of the injury and the need to use a multi-modal rehabilitation approach to return to full healing of the ligament.

In comparison to Case 1, the combined use of hydrotherapy and fitness in Peshawar was significantly more sophisticated and comprehensive. Peshawar's rehabilitation program employs a deeper level of aquatic rehabilitation than Case 1 through the use of underwater treadmill training, lateral agility exercises in the water, and a structured gym-based fitness program that focuses on building posterior chain strength (hamstrings and glutes) necessary for ACL injury prevention.

OUTCOME

Full recovery achieved at 6 months / 20 sessions. Peshawar demonstrated symmetrical strength ratios (quadriceps and hamstrings), negative Lachman and Pivot Shift tests, and clearance for return to competitive sport.

Phase Rehabilitation Timeline

Phase	Duration	Goal	Key Exercises
Phase 1	Months 1–	Tissue	TECAR, TENS, infrared, gentle

Phase	Duration	Goal	Key Exercises
	2(6 sessions)	healing, pain & swelling control	aquatic ROM, non-weight-bearing pool exercises
Phase 2	Months 2–4(8 sessions)	Neuromuscular strength	Aquatic treadmill, pool squats, bilateral leg press, hamstring curls, hip thrust, core stability
Phase 3	Months 4–5(4 sessions)	Functional training	Pool lateral drills, single-leg balance, aquatic plyometrics, Bulgarian split squat, RDL
Phase 4	Month 6(2 sessions)	Return to sport	5-10-5 shuttle, cutting drills, sport-specific agility, return-to-sport criteria testing

CASE 3 — Kahraman Ahmad

ACL Injury | Comprehensive Long-Term Rehabilitation

Patient Profile

Full Name	Kahraman Ahmad
Age	21 years
Diagnosis	ACL Injury (Significant — Extended Management)(Partial Tear)
Sessions Completed	35 Sessions
Rehabilitation Duration	8 Months
Outcome	Full recovery — cleared for high-level sport return
Management Type	Conservative (Non-surgical) — Intensive Protocol

Modalities Used

□TENS(Electrical Stimulation)	□Infrared Therapy(Near-Infrared)	□Hydrotherapy(Intensive Aquatic)	□Fitness Training(Advanced Progressive)

Clinical Rationale

This case (Kahraman) is the most complicated within this study. He had 35 therapy appointments in a period of 8 months, which can be attributed to one of three reasons - either he had a much greater degree of injury than the subject matter already discussed, his healing was delayed due to slower initial healing response or he had more functional demands being placed upon him (returning to sport). The time period of 35 therapies same length timeframe permitted the therapist to progress through all of the stages of rehabilitation without cutting endless corners thus reducing the chances that an athlete would be re-injured.

The hydrotherapy and fitness training protocol for Kahraman represented the largest volume (35 sessions) of therapy relative to any of the other two cases, allowing greater attention to neuromuscular re-education, proprioceptive training and advanced sport- specific conditioning, all common areas in rehabilitation that are often neglected due to time constraints.

Additionally, the extended duration of 8 months allowed for complete maturation of the graft (i.e., remodeling of ligaments) prior to beginning to apply high load sport-specific demands. Research has shown that returning to sport with only partial neuromuscular recovery is one of the most prevalent modified risk factors for a re-curred ACL injury (Ardern et al., 2014; Kyritsis et al., 2016); therefore, Kahraman's extended rehabilitation program is surrounded by best practices for a competitive athlete returning to his sport.

OUTCOM

Full recovery at 8 months / 35 sessions. Kahraman achieved >90% limb symmetry index on strength testing, passed all return-to-sport criteria, and was discharged with a home maintenance program.

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Phase Rehabilitation Timeline

Phase	Duration	Goal	Key Exercises
Phase 1	Months 1–2(8 sessions)	Acute care, healing, pain management	TENS, infrared, gentle aquatic ROM, isometric exercises, edema control
Phase 2	Months 2–4(10 sessions)	Strength & mobility restoration	Aquatic treadmill, pool squats, leg press, hamstring/quad strengthening, core program
Phase 3	Months 4–6(10 sessions)	Functional & neuromuscular training	Aquatic plyometrics, single-leg training, agility, Bulgarian split squat, RDL, sled work
Phase 4	Months 6–8(7 sessions)	Return-to-sport conditioning	Full gym progressive overload, change-of-direction, sport drills, cardiovascular intervals

Comparative Analysis of the Three Cases

Parameter	Ahmad (Case 1)	Peshawar (Case 2)	Kahraman (Case 3)
Age	18 years	22 years	21 years
Injury Severity	Sprain (Grade I/II)	Partial Tear (Grade II)	Significant ACL Injury
Sessions	12	20	35
Duration	3 months	6 months	8 months
Sessions/Month	4.0	3.3	4.4
Primary Modality	TENS + Ultrasound	TECAR + Infrared	TENS + Infrared
Hydrotherapy	Yes	Yes	Yes (Intensive)
Fitness Program	Basic	Moderate	Advanced

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Parameter	Ahmad (Case 1)	Peshawar (Case 2)	Kahraman (Case 3)
Outcome	Full recovery	Full recovery + sport	Full recovery + sport

Overall, hydrotherapy was present throughout the rehabilitation of patients in all three cases. The data suggest that there are valuable aspects of hydrotherapy from beginning to end during conservative ACL rehabilitation. Hydrotherapy is a part of acute pain and swelling management at the beginning of rehabilitation and a part of advanced proprioceptive and plyometric training during the final rehabilitation stages.

An example of how duration and intensity of rehabilitation need to correspond with severity of injury and functional needs of the patient can be seen in the difference between Case 1 (12 treatments) and Case 3 (35 treatments). All three patients were able to return to full function, thus showing that when used with the proper dosage, conservative management is effective.

Step-by-Step Physiotherapy Modality Protocols

Physical therapy treatments constitute the basis of physical rehabilitation in the initial stages of rehabilitation in each of the three cases. They may be used pre- and/or post-exercise, and serve to relieve pain, decrease inflammatory reaction, stimulate tissue regeneration, and promote activation of muscles and nerves. Each treatment modality is provided with clinical rationale, treatment parameters and step-by-step approach to provide therapy.

1. TENS — Transcutaneous Electrical Nerve Stimulation

Used in: Case 1 (Ahmad) — Sessions 1–6 | Case 2 (Peshawar) — Sessions 1–8 | Case 3 (Kahraman) — Sessions 1–12

MECHA TENS delivers low-voltage electrical impulses through skin electrodes to activate sensory nerve fibers. Pain relief occurs through two mechanisms: (1) Gate Control Theory — high-frequency stimulation (80–150 Hz) closes the pain gate in the dorsal horn of the spinal cord; (2) Endorphin Release — low-frequency stimulation (2–10 Hz) triggers

NISM	endogenous opioid release for longer-lasting analgesia (Fitzgerald et al., 2003).

TENS — Step-by-Step Application Protocol

#	Exercise	Dose	Instructions
1	**Patient Positioning**	2–3 min	Position patient comfortably supine or sitting with knee fully exposed. Remove all metal objects near the knee. Inspect skin for integrity — do NOT place electrodes over open wounds, broken skin, or areas of sensory loss.
2	**Electrode Placement**	2 min	Using an alcohol swab, cleanse the skin thoroughly before allowing it to dry completely. Four electrodes should be placed on or around the knee as follows: (A) Bipolar - Place two pairs of electrodes on the medial joint line and two pairs on the lateral joint line or (B) Crossed - Two channels intersecting at the ACL region, one anterior and one posterior (i.e., they cross each other). Use conductive gel to ensure good electrode to skin contact.
3	**Parameter Selection**	Setup	ACUTE phase (Weeks 1–3): Frequency 80–150 Hz, Pulse Width 50–80 µs — produces tingling without muscle contraction (gate control). SUB-ACUTE phase (Weeks 3+): Frequency 2–10 Hz, Pulse Width 200–250 µs — produces gentle muscle twitch for endorphin release. Always start at zero intensity.
4	**Intensity Calibration**	2 min	Increse intensity gently (the patient should report) "a strong comfortable type of tingle/buzz being produced in an area with/without pain". When using low

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#	Exercise	Dose	Instructions
			frequency TENS, muscle contractions can occur; however, they should only be small muscle twitches and not look unnatural. Once the patient has given you this information, ask them to rate their level of comfort (6 or 7 on a scale from 1-10, 10 being very comfortable).
5	**Treatment Session**	20–30 min	Run for 20–30 minutes. Check patient comfort at 5-minute intervals. Sensation may fade (habituation) — slight increase in intensity is acceptable. Monitor skin under electrodes for redness. Patient may rest, read, or perform passive exercises during treatment.
6	**Post-Treatment Assessment**	3–5 min	Remove electrodes and inspect skin. Ask patient to rate pain (NRS 0–10) before and after and document. Expected: 2–4 point NRS reduction post-session. Note any skin irritation and adjust electrode placement next session. Record all parameters for consistency.

Parameter	High-Frequency TENS	Low-Frequency TENS
Frequency	80–150 Hz	2–10 Hz
Pulse Width	50–80 µs	200–250 µs
Onset of Relief	During session	20–30 min post-session
Duration of Effect	Short-term (hours)	Longer-lasting (6–8 hrs)
Best Phase	Acute (Weeks 1–4)	Sub-acute / Chronic
Primary Mechanism	Gate control	Endorphin release

2. Therapeutic Ultrasound

Used in: Case 1 (Ahmad) — Sessions 1–8 | Recommended phase: Weeks 1–6

MECHANISM

Therapeutic ultrasound transmits high-frequency sound waves into the tissue (either 1 or 3 megahertz). Continuous mode produces thermal effects by elevating tissue temperature by 1 to 4 degrees Celsius, increasing collagen extensibility, promoting increased blood flow, and reducing muscle spasms. Pulsed mode produces non-thermal effects in the form of acoustic streaming and cavitation, allowing for increased cell membrane permeability, hastening collagen production, and aiding in the healing process on a cellular level, which is vitally important for collagen repair.

Therapeutic Ultrasound — Step-by-Step Application Protocol

#	Exercise	Dose	Instructions
1	**Preparation & Safety**	2–3 min	Confirm no metal implants in treatment area (absolute contraindication). Position patient supine, knee slightly flexed over a pillow. Check skin integrity. Confirm the patient can report heat or pain reliably — required for safe application.
2	**Frequency Selection**	Setup	Select 3 MHz for superficial structures (0–3 cm depth) — preferred for ACL peri-articular tissue. Select 1 MHz for deeper penetration (>3 cm) in larger/more muscular patients. For most ACL cases, 3 MHz at the joint line is standard.
3	**Mode Selection**	Setup	ACUTE (Weeks 1–3): Pulsed mode, 20% duty cycle (1:4 pulse ratio) — maximizes non-thermal healing effects with minimal heat. SUB-ACUTE (Weeks 3–6): Continuous mode — thermal effect increases tissue extensibility and drives remodeling of healing collagen fibres.
4	**Intensity Setting**	Setup	Pulsed mode: 0.5–1.0 W/cm² (SATA). Continuous mode: 1.0–1.5 W/cm². Patient

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#	Exercise	Dose	Instructions
			should feel mild warmth at most in continuous mode — burning or significant heat indicates intensity is too high. Reduce immediately if reported.
5	**Coupling Gel Application**	1 min	Apply generous coupling gel over medial joint line, lateral joint line, and anterior knee. Eliminate all air between transducer and skin. For bony prominences or irregular surfaces, immerse limb in a basin of degassed water (underwater technique) as an alternative.
6	**Transducer Technique**	5–8 min	You must move transducer continuously in slow, overlapping circles (diameter 2-3 cm). Do not allow it to remain still; the stationary application creates standing waves and creates focal hot spot areas of tissue damage. Maintain the transducer head at a 90-degree angle with respect to the skin's surface. You should cover the treatment area 2-3 times the size of the transducer's effective radiating area (ERA).
7	**Dosage Calculation**	Per session	Time = (Treatment Area cm^2) ÷ (Transducer ERA cm^2) × 1–2 minutes. Typical knee treatment: 5–8 minutes per zone. Treat medial and lateral joint lines as separate zones. Total knee session: 10–16 minutes for full coverage.
8	**Post-Treatment**	2 min	Remove gel. Note any skin changes. Ideal timing: perform stretching or joint mobilization immediately after US while tissue is warm and extensible. Document: frequency, mode, intensity, duration, area treated, and patient response.

3. TECAR Therapy (Capacitive and Resistive Energy Transfer)

Used in: Case 2 (Peshawar) — Sessions 1–12 | Particularly effective for deeper ligament tissue healing in partial tears

MECHANISM

The two different modes of the Tecnology de Ionic Generatives used to create deep endogenous hyperthermia are capacitive (CAP) and resistive (RES). The CAP mode is used for superficial tissues such as muscles, tendons and skin. The RES mode will penetrate lower water-content tissues such as ligaments, cartilages and bones. Utilizing TECAR can provide greater depth than traditional ultrasound due to the generation of deep endogenous hyperthermia.

TECAR Therapy — Step-by-Step Application Protocol

#	Exercise	Dose	Instructions
1	**Patient Setup**	3–5 min	Remove all metal jewelry and electronic devices. Position patient supine, knee exposed. Place large grounding return electrode (plate) under the thigh or calf with good skin contact. Check contraindications: cardiac pacemaker, metal implants at treatment site, active infection, pregnancy, malignancy.
2	**Mode Sequence: CAP → RES**	Per session	Commencing in CAP (5-7 minutes) mode will target multiple muscle groups - quadriceps and hamstrings - plus support superficial joint structure by preparing tissue and increasing circulation within that area. Transition next into RES (10-12 minutes) mode to create penetration into the tissues at the deepest levels in order to treat areas where greater need of healing occurs, such as the ACL, joint capsule, and subchondral bone.
3	**Acute Phase Parameters**	Weeks 1–4	Temperature target: 38–39°C (mild hyperthermic — anti-inflammatory

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#	Exercise	Dose	Instructions
			range). Power: 30–50% device maximum. Gentle continuous circular motion. Goal: reduce edema, inhibit pro-inflammatory cytokines, support early-phase tissue repair without excessive thermal loading.
4	**Sub-Acute Parameters**	Weeks 4–12	Desired temperatures of 40-42°C (moderately hyperthermic - remodeling range). Energy levels of 50 to 75% of max output on the device. Higher intensities will promote fibroblast proliferation, collagen restructuring, and vascular proliferation within the ligaments as they heal. Patient experiences very clear, comfortable warmth through out their joint.
5	**Applicator Technique**	15–20 min total	Apply coupling gel or oil. Move applicator continuously in overlapping circles (3–5 cm diameter, 1–2 circles/sec). Cover: anterior knee, medial and lateral joint lines, posterior knee capsule. NEVER stop movement — stationary application causes localized overheating. Maintain firm but gentle contact pressure.
6	**Dynamic TECAR Application**	Final 5–8 min	Advanced technique: apply TECAR while patient performs gentle active knee flexion/extension or therapist applies passive mobilization. Movement during heating enhances deep tissue remodeling and is superior to static application for ligament repair. Introduce after 3–4 sessions when patient is comfortable with the modality.
7	**Post-Treatment**	3–5 min	Allow tissue to cool 2–3 minutes. Remove gel. Immediate therapeutic window: heated tissue is maximally extensible — perform passive stretching or manual joint mobilization directly after TECAR.

#	Exercise	Dose	Instructions
			Document power settings, modes used, temperature reached, duration, and patient response.
TECAR vs ULTRASOUND	TECAR penetrates 2–3× deeper than therapeutic ultrasound, making it the modality of choice for ACL and deep intra-articular tissue, especially in athletic patients with greater muscle mass where surface modalities have limited reach.		

4. Infrared Therapy (Near-Infrared / Photobiomodulation)

Used in: Case 2 (Peshawar) — Sessions 1–10 | Case 3 (Kahraman) — Sessions 1–15

MECHANISM	NIR light in the range of 750 nm - 1200 nm penetrates 2 - 7 cm into tissue. Cytochrome C oxidase in mitochondria absorbs NIR photons, promoting ATP synthesis, reducing oxidative stress and regulating inflammatory cytokines (Ferraresi et al., 2024; Lima et al., 2022). The result is accelerated tissue repair, analgesia, improved microcirculation and increased collagen production- all of which are critical for healing an ACL ligament. NIR is complementary to TECAR and TENS when used in multimodal protocols.

Infrared Therapy — Step-by-Step Application Protocol

#	Exercise	Dose	Instructions
1	**Safety Check**	2–3 min	Provide protective goggles to patient and therapist — MANDATORY with all infrared devices. Assess skin for photosensitizing medications (tetracyclines, some NSAIDs). Check for any tattoos in the treatment area (may absorb excessive energy). Position patient supine, knee fully exposed, skin clean and free of creams or oils.
2	**Device Positioning**	1–2 min	Position infrared lamp/panel at 30–50 cm from the knee surface (per manufacturer specification). For focused treatment, use LED cluster probes or laser applicators. Ensure the beam is perpendicular to the target tissue for maximum tissue penetration efficiency. Mark treatment zone boundaries if needed.
3	**Dose Parameters**	Setup	Optimal wavelength: 810–850 nm (near-infrared). Anti-inflammatory dose: 4–6 J/cm². Tissue repair dose: 8–12 J/cm². Power density: 50–200 mW/cm². Calculate treatment time: Time (s) = Dose (J/cm²) × 1000 ÷ Power (mW/cm²). Example: 8 J/cm² at 100 mW/cm² = 80 seconds per zone.
4	**Acute Phase Application**	8–10 min	Weeks 1–4: lower dose (4–6 J/cm²), standard distance, focus on medial and lateral joint lines. NIR inhibits prostaglandin synthesis and reduces TNF-α, IL-1β cytokine release — powerful anti-inflammatory complement to TENS without any systemic side effects.
5	**Sub-Acute Phase Application**	10–15 min	Weeks 4–12: higher dose (8–12 J/cm²), wider coverage including ACL region, posterior capsule, and periarticular muscles. NIR at therapeutic doses

#	Exercise	Dose	Instructions
			promotes fibroblast proliferation and Type I collagen synthesis — the structural collagen that rebuilds the ligament matrix.
6	**Treatment Monitoring**	Continuous	Patient should feel mild warmth or nothing at all — NOT heat or burning. Check skin every 3–4 minutes for erythema. If burning sensation reported, increase distance immediately. Unlike TECAR, IR therapy requires minimal patient feedback for safe delivery — patient simply rests under the lamp.
7	**Post-Treatment**	2–3 min	Remove goggles. Inspect skin. Allow 2–3 minutes rest. NIR creates a 4–6 hour window of enhanced cellular metabolism post-treatment — advise patient that gentle active exercise or walking during this window potentiates therapeutic effects. Document wavelength, dose, duration, area, and response.

Modality	Penetration Depth	Optimal Phase	Key Benefit
TENS	Superficial nerves	Weeks 1–8	Immediate pain relief
Ultrasound	0–5 cm	Weeks 1–6	Collagen synthesis / thermal
TECAR	5–10+ cm	Weeks 1–16	Deep ligament remodeling
Infrared (NIR)	2–7 cm	Weeks 1–12	ATP / tissue repair

5. Manual Therapy & Exercise Facilitation

R Electrophysical modalities can be complemented by manual therapy

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techniques across the three cases referred to above. The specific techniques used are patellar mobilization (a way to help prevent post-injury stiffness), tibiofemoral joint mobilization (using Grades I–II to reduce pain and Grades III-IV to improve range of motion), soft tissue massage of the quadriceps, iliotibial band, and gastrocnemius muscles (to reduce muscle guarding), and neural mobilization (for sciatic nerve sensitization).

#	Exercise	Dose	Instructions
1	**Patellar Mobilization**	3×30 sec each direction	Patient supine, quadriceps relaxed, knee fully extended. Apply gentle oscillating pressure gliding the patella superiorly, inferiorly, medially, and laterally. Grade I–II for pain; Grade III–IV for stiffness. Essential to prevent patellar adhesions and maintain normal knee biomechanics.
2	**Tibiofemoral Distraction**	3×30 sec	Patient supine, knee in 25° flexion (resting position). Grasp tibia distally and apply gentle longitudinal traction. Reduces intra-articular pressure, provides pain relief via mechanoreceptor stimulation, and promotes synovial fluid circulation for cartilage nutrition.
3	**Quadriceps Soft Tissue Release**	5 min	Patient supine or prone. Apply sustained pressure to trigger points in rectus femoris and vastus medialis oblique. Releases muscle guarding that inhibits voluntary quadriceps activation after injury. Follow immediately with active quad contraction exercise to reinforce neural recruitment.
4	**Passive Hamstring Stretching**	3×40 sec holds	Patient supine. Therapist raises leg with knee extended until hamstring tension felt. Hold 40 seconds at end-range. Hamstring flexibility is critical for ACL protection — tight hamstrings alter tibiofemoral kinematics and increase anterior tibial shear forces. Perform after every session.
5	**Neural**	3×10	Straight leg raise position. Patient

#	Exercise	Dose	Instructions
	Mobilization (Sciatic)	reps	alternates ankle dorsiflexion (increases neural tension) and plantar flexion (releases). Oscillatory movement of the neural tract addresses sciatic nerve sensitization that accompanies ACL injury and contributes to persistent pain and muscle inhibition.

Step-by-Step Hydrotherapy Protocols

The protocols below have been outlined for clinical use during research studies and in practice with no modifications other than to account for heating and depth of water. The therapeutic swimming pool setting will have a temperature of 33-35 degrees. The level of water can change to decrease or increase the amount of weight bearing during each session. Each session will last 45-60 minutes.

PHASE 1 — Early Aquatic Rehabilitation (Weeks 1–4)

GOAL	Pain and edema control, restore gentle range of motion, prevent muscle atrophy, build patient confidence in movement. Pool depth: chest-deep (25% body weight).

Exercise Sequence — Phase 1

#	Exercise	Dose	Instructions
1	**Pool Entry & Warm-Up Walk**	5–7 min	Enter chest-deep warm water (33–35°C). Walk forward and backward slowly. Water depth reduces weight-bearing to ~25% body weight, allowing pain-free gait practice.
2	**Knee Flexion/Extension (Passive ROM)**	3×15 reps	Hold pool edge for support. Gently flex and extend the knee through comfortable range. Buoyancy assists upward movement; gravity assists downward. Do NOT force into pain.
3	**Heel Slides**	3×12	Stand in shoulder-deep water facing pool

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#	Exercise	Dose	Instructions
	(Standing)	reps	wall. Slowly slide heel backward bending the knee, then return. Water resistance is minimal at slow speed — ideal for acute phase.
4	**Hip Abduction & Adduction**	3×15 reps each side	Stand holding pool edge. Raise leg sideways against water resistance, then return. Activates hip stabilizers critical for knee alignment without loading the ACL graft.
5	**Quad Sets (Isometric)**	3×10 reps, 10-sec hold	Sit on pool step or stand in shallow water. Tighten quadriceps muscle, hold 10 seconds, release. Combats arthrogenic muscle inhibition caused by post-op swelling.
6	**Hydrostatic Edema Reduction**	5 min (end of session)	Stand still in chest-deep water. The hydrostatic pressure passively compresses the knee, reducing swelling. Optional: gentle ankle pumps to stimulate venous return.

Phase 1 Notes: Sessions should not exceed 40–45 minutes. Pain during any exercise is the signal to stop — not the goal. Monitor wound closure before pool entry (typically safe from Day 10–14 post-injury/procedure). Water temperature above 36°C is contraindicated for acute inflammation.

PHASE 2 — Aquatic Strengthening & Mobility (Weeks 4–10)

GOAL Progressive lower limb strengthening, restore full ROM, improve neuromuscular coordination, maintain cardiovascular fitness. Pool depth: waist-deep (50% body weight) to chest-deep (25%) depending on exercise.

Exercise Sequence — Phase 2

#	Exercise	Dose	Instructions
1	**Aquatic Treadmill**	10–15 min	Walk on underwater treadmill at 50% body weight (waist-deep water). Begin at

#	Exercise	Dose	Instructions
	Walking		2 km/h, progress speed weekly. Focus on heel-to-toe gait pattern and equal limb loading.
2	**Bilateral Aquatic Squat**	4×12 reps	Stand in waist-deep water, feet shoulder-width apart. Lower to 60° knee flexion, then rise. Water provides resistance on ascent and assistance on descent. Progress to deeper squats weekly.
3	**Single-Leg Mini Squat (Operated Leg)**	3×10 reps	Hold pool wall lightly for balance. Perform mini squat on the operated leg only. Buoyancy allows safe single-leg loading earlier than land-based equivalent.
4	**Lateral Step & Cross-Step**	3×20 steps each direction	Walk sideways through water (lateral shuffle) then crossover steps. Water viscosity creates resistance that strengthens hip abductors and improves frontal-plane knee stability.
5	**Forward/Backward Pool Running**	3×60 sec intervals	Run forward then backward in waist-deep water at moderate intensity. Arms drive for balance. This maintains cardiovascular fitness and activates hamstrings/glutes without high impact.
6	**Aquatic Resistance Band Knee Extension**	3×15 reps	Attach resistance band to pool anchor. Perform knee extension against band resistance while stabilizing with opposite leg. Targets quadriceps in functional range.
7	**Standing Calf Raises**	3×20 reps	Rise up onto toes slowly, hold 2 seconds, lower. Water adds stability challenge. Strengthens calf-soleus complex important for push-off mechanics during return to sport.
8	**Cool-Down: Buoyancy Float**	5 min	Hold pool edge and allow body to float. Gently stretch hip flexors and hamstrings

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#	Exercise	Dose	Instructions
	Stretch		using buoyancy support. Warm water promotes muscle relaxation and tissue extensibility.

Phase 2 Notes: Introduce resistance equipment gradually (aqua dumbbells, resistance bands, paddles). Underwater treadmill, if available, is the preferred cardiovascular training tool. Monitor limb symmetry during all bilateral exercises. Target: operated leg achieves at least 80% of non-operated leg performance before Phase 3.

PHASE 3 — Aquatic Functional & Plyometric Training (Weeks 10–20)

GOAL Proprioception, neuromuscular control, early plyometric loading, sport-specific movement patterns. Pool depth: knee-to-waist deep for plyometrics (maximum absorption), deep water for cardiovascular training.

Exercise Sequence — Phase 3

#	Exercise	Dose	Instructions
1	**Deep Water Running (Pool Noodle)**	3×3 min, 1-min rest	Use flotation belt or noodle in deep water. Run with full arm and leg drive — simulates land running biomechanics at zero impact. Excellent for cardiovascular conditioning.
2	**Single-Leg Balance (Aquatic Unstable Surface)**	4×30 sec each leg	Stand on one leg in waist-deep water. The water's current and turbulence creates an unstable environment challenging proprioceptors. Progress by closing eyes or adding arm movements.
3	**Lateral Bounding (Shallow Water)**	3×10 reps each side	In knee-deep water, perform controlled lateral hops from one foot to the other. Water decelerates landing forces, allowing early plyometric training 4–6 weeks before land equivalent.

#	Exercise	Dose	Instructions
4	**Forward Hop & Stick (Aquatic Plyometric)**	3×8 reps	Hop forward on one leg, land and hold position for 3 seconds ('stick'). Water absorbs shock and reduces fear response. Develops landing mechanics and neuromuscular control.
5	**Underwater Treadmill: Jogging Intervals**	5×2 min jog / 1-min walk	Jog at 4–6 km/h on underwater treadmill. Focus on symmetrical push-off and arm swing. Heart rate target: 65–75% maximum. Progress incline and speed weekly.
6	**Diagonal Cross-Cut Drills**	3×8 reps each direction	In chest-deep water, step diagonally forward-left then pivot right (mimics cutting movements in sport). Water slows movement, teaching correct trunk and knee alignment during direction change.
7	**Aquatic Step-Up & Step-Down**	3×12 reps each leg	Use underwater step platform. Step up onto platform with operated leg, controlling descent slowly. Eccentric loading in water is safe and highly effective for quadriceps strength.

Phase 3 Notes: Aquatic plyometrics can typically be introduced 4–6 weeks earlier than equivalent land-based plyometrics, accelerating return-to-sport timelines (Buckthorpe et al., 2019; Physiopedia, 2024). All jumping and hopping exercises should demonstrate a 'quiet' controlled landing before progression. If any exercise provokes pain greater than 3/10 NRS, regress to the previous phase.

Step-by-Step Fitness / Land-Based Protocols

The fitness program complements hydrotherapy by addressing strength domains that water training develops less effectively — particularly hamstring and posterior chain strength, heavy compound loading, plyometric power, and sport-specific agility. Sessions are typically 50–75 minutes and conducted on non-consecutive days with hydrotherapy.

FITNESS PHASE 2 — Foundation Strength (Months 2–4)

GOAL Rebuild bilateral and unilateral lower limb strength, address quadriceps-hamstring imbalance, establish core stability foundation. All exercises performed with pain-free range of motion only.

Exercise Sequence — Fitness Phase 2

#	Exercise	Dose	Instructions
1	**Stationary Bike (Low Resistance)**	15–20 min	Set seat high so knee flexion does not exceed 90°. Low resistance, steady cadence (60–70 RPM). Maintains cardiovascular fitness and lubricates the knee joint through cyclic motion.
2	**Leg Press (Bilateral)**	3×15 reps	Begin at 40–50% of 1RM. Feet parallel, shoulder-width. Press through full foot — do not lock knee at full extension. Range of motion: 0–60° initially, progress to 90°.
3	**Hamstring Curl (Lying)**	3×12 reps	Critical to address aquatic hamstring limitation. Use cable or machine. Curl from full extension to 90° flexion slowly. 3-second eccentric (lowering) phase. Start light, progress weekly.
4	**Hip Thrust (Bodyweight → Loaded)**	3×15 reps	Upper back on bench, feet flat on floor. Drive hips up, squeeze glutes at top, hold 2 seconds. Gluteal strength is critical for knee valgus control and ACL protection.
5	**Calf Raise (Machine or Step)**	4×20 reps	Full range: from heel drop to full plantar flexion. Add bodyweight load progressively. Strong plantarflexors improve push-off efficiency and reduce compensatory loading patterns.
6	**TRX/Suspension Squat**	3×12 reps	Hold TRX straps for stability support. Perform controlled squat to 70–80°. Straps allow trunk support while developing lower

#	Exercise	Dose	Instructions
			limb strength with proper knee tracking.
7	**Core: Dead Bug**	3×10 reps each side	Lie on back, arms and legs at 90°. Lower opposite arm and leg slowly while keeping lower back flat. Core stability is foundational for safe knee loading during sport.
8	**Core: Side Plank**	3×30 sec each side	Elbow side plank, body in straight line. Focuses on hip abductors (gluteus medius) which prevent medial knee collapse — a primary mechanism of re-injury in ACL athletes.

Fitness Phase 2 Notes: Initial loads should allow 15 reps with 2–3 reps in reserve (RPE 6–7/10). Increase load by 5–10% when 15 reps can be completed with good form across 3 consecutive sessions. Hamstring curl is a priority — the hamstring-to-quadriceps strength ratio (H:Q ratio) should approach 0.55–0.65 before Phase 3 progression.

FITNESS PHASE 3 — Advanced Strength & Return-to-Sport (Months 4–8)

GOAL	Develop unilateral strength, explosive power, change-of-direction mechanics, and sport-specific conditioning. Target: >90% limb symmetry index (LSI) on all strength and functional tests.

Exercise Sequence — Fitness Phase 3

#	Exercise	Dose	Instructions
1	**Bulgarian Split Squat**	4×10 reps each leg	Rear foot on bench, front foot forward. Lower until front thigh is parallel to floor. Builds unilateral lower limb strength and exposes asymmetry between legs. Add dumbbells progressively.
2	**Romanian**	4×10	Hold barbell/dumbbells. Hinge at hips,

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#	Exercise	Dose	Instructions
	Deadlift	reps	send hips back, lower weights close to legs, hamstrings stretch, return. Develops posterior chain strength critical for ACL protection.
3	**Box Step-Up (Eccentric Emphasis)**	4×8 reps each leg	Step up with operated leg, drive knee up, then slowly lower the opposite foot for 4–5 seconds. Eccentric quad loading is the most effective stimulus for quad strength recovery.
4	**Sled Push/Pull**	4×20 metres	Push loaded sled forward (quad dominant) then drag backward (hamstring dominant). Horizontal force production mirrors sprint and cutting demands. Begin light, progress load weekly.
5	**Plyometrics: Box Jump (Bilateral)**	4×8 reps	Jump from ground to box, land softly with knees over toes. Step down — do NOT jump down. Focus on quiet, controlled landing before adding height. Develop elastic power progressively.
6	**Plyometrics: Broad Jump**	3×6 reps	Two-foot takeoff, maximum horizontal distance. Land with bent knees, hips back, soft landing. Measures and develops horizontal power — strongly correlated with return-to-sport readiness.
7	**Agility Ladder Drills**	4×3 patterns, 60 sec rest	Perform in-in-out-out, lateral shuffle, and single-leg hop patterns. Develops foot speed, coordination, and neuromuscular responsiveness. Progress from slow to sport speed.
8	**Change of Direction: 5-10-5 Shuttle**	5×reps, 90 sec rest	Sprint 5m right, touch line, sprint 10m left, touch line, sprint 5m back. Timed. Develops acceleration, deceleration, and lateral change-of-direction mechanics under controlled fatigue.
9	**Cardiovascular**	20–30	Treadmill or track. Pattern: 2 min at 70%

#	Exercise	Dose	Instructions
	: Interval Running	min	max HR, 1 min at 85% max HR. Progress weekly. Restore sport-specific aerobic capacity needed for full match/competition return.

Fitness Phase 3 Notes: Plyometric volume should follow a 10% weekly progression rule — do not increase sets AND height AND speed simultaneously. Agility drills should be introduced at 75% maximum speed, progressing to 100% only when mechanics are consistent. Sport-specific drills (dribbling, passing, court movements) are introduced in the final 4–6 weeks before return-to-sport clearance.

Return-to-Sport Discharge Criteria

Regardless of rehabilitation duration, all three patients were assessed against objective return-to-sport criteria before discharge. These criteria ensure that discharge decisions are evidence-based rather than solely time-dependent (Grindem et al., 2016; Kyritsis et al., 2016; Myer et al., 2006).

Criterion	Target Standard	Assessment Tool
Quadriceps Strength Symmetry	>90% Limb Symmetry Index (LSI)	Isokinetic Dynamometer
Hamstring Strength Symmetry	>90% LSI	Isokinetic / NordBoard
Hamstring-to-Quadriceps Ratio	>0.55 (H:Q ratio)	Dynamometer
Single-Leg Hop (Distance)	>90% LSI	Single-Hop Test
Triple Hop for Distance	>90% LSI	Triple-Hop Test
Pain During Activity	0/10 NRS at full activity	Numeric Rating Scale
Knee Stability	Negative Lachman & Pivot Shift	Clinical Examination
Psychological Readiness	>85% ACL-RSI Score	ACL-RSI Questionnaire

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Criterion	Target Standard	Assessment Tool
Full ROM	Equal to non-operated side	Goniometry
Change-of-Direction Speed	<10% deficit vs non-operated	5-10-5 / T-test

Conclusion

The three case studies provided illustrate how effective a conservative multimodal approach to rehabilitate ACL injuries of varying severity was. The use of hydrotherapy, physiotherapy modalities, and progressive fitness training throughout the course of three case studies resulted in complete functional recovery, and the duration of rehabilitation was proportionate to the severity of each injury.

The stepwise hydrotherapy and fitness protocols outlined in this document provide clinicians with a clinically relevant and evidence-based treatment framework that is adaptable to the patient population in which they treat. The following principles were utilized in developing these protocols: 1) Early initiation of aquatic therapy for the purpose of reducing pain and swelling; 2) Progressive weight loading based on pain response and functional milestones; 3) Combining aquatic and land-based training in a hybrid approach; 4) Objective testing prior to discharge to determine an athlete's readiness to return to sport.

The importance of hydrotherapy is evidenced by the commonality of its use in all case studies regardless of the number or duration of sessions. Future studies are needed to evaluate the optimal dosage of aquatic therapy and the effect of hybrid rehabilitation on rates of re-injury and quality of life in ACL patients over time.

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