

RETURN TO SPORT FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: WOMEN'S INDOOR VOLLEYBALL

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Women's volleyball participation has increased over the past four decades resulting in a rise of sports-related injuries during practice and competition. Although volleyball is considered a non-contact sport, the sport requires jumping, landing, pivoting, directional changes and digging, which can lead to anterior cruciate ligament (ACL) injury and reconstruction. There are limited studies on guidelines for safe return to volleyball competition after an ACL injury. A volleyball-specific functional rehabilitation program is critical for optimal return to sport following ACL reconstruction. A volleyball athlete must be trained and proficient in jumping and landing to serve, hit and block as well as pivot, cut and change direction on the court to retrieve balls or prepare a set. Proper landing mechanics from a jump become a crucial part of post-operative ACL rehabilitation to avoid re-injury and ensure safe return to competitive sport. A critical part of ACL rehabilitation is following a criteria-based approach exhibiting progressions in range of motion, mobility, strength, neuromuscular control, agility and cardiovascular training. Incorporating volleyball-specific skills early in the athlete's rehabilitation program allows re-training of important skills during a time when the athlete is removed from play. Volleyball-specific tasks can be integrated early in proprioceptive and neuromuscular training drills and eventually progressed towards more challenging court-based tasks as the athlete advances through the phases of their rehabilitation program. Collaboration and communication of a multidisciplinary team made up of physicians, physical therapists, athletic trainers, strength and conditioning specialists, coaches and parents must work together to determine an athlete's readiness for return to sport (RTS). It is important to take into consideration the athlete's sport, risk of re-injury, demands of the sport and their psychological readiness when facilitating RTS decisions.

Volleyball has become a very popular sport internationally with team participation ranging from youth club to professional leagues¹. In the United States, volleyball has developed into the number one team sport for girls in high school and college, with indoor volleyball the most popular form². Women's collegiate indoor court volleyball is the second most sponsored National Collegiate Athletic Association (NCAA) team with 96% of schools sponsoring a team³. The first sanctioned women's NCAA indoor volleyball championship was held in 1981⁴. During the 1988-1989 season, 721 sponsored women's volleyball teams played with 9,486 participants. Women's NCAA volleyball participation has continued to gain popularity and

in the 2014-2015 season, sponsored teams grew to 1,071 with 17,026 participants¹. Girls' high school volleyball student-athlete participation has also expanded by 8.4% from 2003-2004 to 2013-2014 academic years, to 429,634 participants, making it the third most popular participation sport behind basketball and outdoor track and field^{5,6}. The number of female volleyball players in high school and college levels has risen over the last two decades⁵. With increased participation, there is a higher risk of sustaining a volleyball-specific injury. It is important for clinicians to be familiar with the unique qualities of indoor volleyball to optimize rehabilitation and treatment strategies for their volleyball athletes.

Indoor volleyball is a team-based sport played on a hard-surface court with two teams configured on either side of the net. Court width is nine meters wide and eighteen meters long with a net at the center line equally dividing the two teams' side of play. Each team has six players per side, usually three players in front and three in back separated by a three-meter line on the court. Front row players can jump and attack at the net, but back row players only attack behind the three-meter line mostly in a defensive position. All players rotate clockwise through the six positions, which is called "serving order." Points are scored by sending the ball over the net with the goal of the ball hitting the ground inbounds on their opponent's side to end each rally⁷.

The game starts by a player successfully serving the volleyball from behind the back line over the net inbounds to the opponent's side. The receiving team has up to three contacts to send the ball back over the net. The three basic contacts are a pass/dig, set and spike/attack. As the ball goes over the net, the opposite team may try to block the ball by jumping up at the net with one or multiple front row players. A player touching any part of the net is a violation, resulting in the opposing team receiving a point and getting the ball back to serve. Any ball landing out of bounds is a point for the opposing team, however a player can run out of bounds to pass the ball into continued play. A rally will continue until a team makes a "kill" by grounding the ball on their opponent's court or a team commits a fault and loses the rally. The team who wins the rally receives a point and serves the ball to begin the next rally. At this time players rotate clockwise around the court and substitutions of players can be made before the next serve begins. The ball can be passed with any part of a player's body but cannot be held, thrown or pushed⁷.

Volleyball is considered a non-contact sport as players are separated by a net and play on their respective sides. One might think injury would be low as opposing teams are separated from direct contact play. However, due to the nature of the sport requiring rapid and forceful full-body movements in horizontal and vertical directions, injuries are bound to happen. Most injuries in volleyball occur in the lower extremity and to the athletes in the front three positions on the court where the most jumping and landing take place^{1,4,10}. Knee injuries are second most common after ankle injuries^{1,4,8,9}, and may occur when jumping, landing, hitting, blocking, passing or setting the ball^{3,11}.

Most ACL injuries take place in non-contact situations when an athlete is cutting, pivoting, suddenly decelerating or landing from a single leg jump^{12,13}. In volleyball, ACL injuries occur frequently when landing from a jump. Female volleyball athletes have been found to have a higher incidence of ACL injuries compared to their male counterparts, with increased risk landing single-leg compared to double-leg¹⁴. An athlete lands from a block in either double-leg or in single-leg stance. If a block is unsuccessful, the athlete may land and step back followed by multiplanar movements such as cutting, pivoting or a stop then jump task to keep the ball in play^{14,15}. Stepping back exposes the back-limb to a greater risk of ACL injury due to a valgus and externally rotated knee position¹⁵. A study by Zahradnik et al confirmed that volleyball athletes landing with knee flexion angles less than thirty degrees had higher ground reaction forces and knee joint stiffness. This decreases the athlete's ability to dissipate forces in the knee, resulting in a higher load and strain on the ACL¹⁴.

Females have been shown to land with greater knee extension, hip extension and knee valgum increasing their risk for ACL injury¹³. A retrospective epidemiological study by Takahashi et al found the number of non-contact ACL injuries was significantly higher than the rate of contact injuries in volleyball. A major mechanism of ACL injury in the female volleyball athlete occurs when landing from a jump attack. These studies suggest routine jump-landing training with volleyball athletes is crucial to reducing the risk of ACL injury and should be integrated into post-operative ACL rehabilitation.

ACL injuries are one of the most common knee injuries in sport, with incidence doubling over the last two decades¹⁷. Female athletes have a 2-8 times higher incidence of ACL injury compared to their male counterparts¹⁸. Several studies have demonstrated female athletes may be at an increased risk due to factors such as genetic predisposition, hormone levels, narrow notch width, and cutting and landing biomechanical differences¹². Many studies have shown female athletes perform tasks such as landing from a jump, cutting and pivoting with decreased hip and knee flexion, increased knee valgus, increased hip internal rotation and increased tibial external rotation. This results in decreased knee stiffness due to high quadriceps to hamstring activity^{12,18,19}. These neuromuscular risk factors have been shown to be modifiable through neuromuscular training²⁰,

which becomes an essential part of post-operative ACL rehabilitation especially in the volleyball athlete who has to jump, land and pivot on the court.

RTS decisions must be a collaborative effort by clinicians, athletes, coaches, families and in some instances, organizations and management^{20,21}. These decisions should be guided by research evidence, athlete performance and clinical expertise²¹. An important role in RTS decision-making is a battery of functional and sport-specific conditioning tests that correlate with the athlete's sport^{20,21}. Observation of sport-specific drill performance is critical for RTS decision making²³. Clearance should not solely be made by quantitative data of the athlete's performance, but more importantly qualitative assessment of movement patterns during sport-specific tasks²⁰. Equally significant is the athlete's psychological readiness to return to sport after an ACL injury²¹⁻²³. Progression through a rehabilitation program should be criteria-based verses time-based to ensure the athlete has the proper range, strength, proprioception, motor control and quality of movement to progress to the next phase of rehabilitation and eventually return to full performance^{22,24-26}. There is a need for a multifactorial RTS framework and standardized objective criteria to guide these decisions^{22,24,27,28}.

In the literature, there are a multitude of guidelines for physical therapy after ACL reconstruction. However, there is little consensus in an optimal rehabilitation program and limited guidance in the later phases when returning an athlete to sport^{24,30-35}. Although there has been a rise in indoor volleyball participation, there is limited available literature to guide the volleyball athlete through the later phases of ACL rehabilitation to full play. Different from other sports, the volleyball athlete must be competent in serving, blocking, hitting and digging. They must be able to proficiently land from a jump then quickly change direction when the ball continues in play. Early integration of rotator cuff and periscapular strengthening, along with rotational core stability drills are needed to maintain hitting and serving power. The purpose of this manuscript is to provide recommendations to guide clinicians working with a volleyball athlete after an ACL reconstruction through all phases of rehabilitation to full RTS.

SPORT-SPECIFIC REHABILITATION PHASES

Post-operative rehabilitation can be divided into five stages that include early post-operative management to late phase RTS guidelines. Phases are focused on criteria-based progressions to ensure an athlete has met the appropriate criteria for each stage of rehabilitation. This allows progressions to be standardized, objective and create realistic expectations for the athlete, parents, coaches, medical team and others involved in RTS decisions. The purpose of this clinical commentary is to review late phase ACL rehabilitation to help guide clinicians in optimal treatment and management for the female volleyball player. In early post-operative management due to the acuity from surgery there is little specialization. Phase 1 and 2 will be briefly discussed including volleyball-specific considerations. This article will primarily focus on Phases 3 through 5.

PHASE 1: PROTECTION AND MOBILITY

In Phase 1, the primary focus is edema control, pain management, range of motion, patella mobility and quadriceps activation. Individual precautions and contraindications are determined by graft type, concomitant procedures and surgeon preference. Communication with the surgeon is critical to know weight-bearing status, brace wear and specific characteristics such as scar tissue seen during surgery that may affect the athlete's early rehabilitation. Refer to Table 1a for full Phase 1 recommendations.

Suggested Rehabilitation Program for Phase 1:

Once swelling, range of motion, gait and strength goals have been achieved, the athlete can initiate volleyball-specific training towards the end of Phase 1. To meet the demands of the sport, initiating upper chain and rotational core strength exercises is crucial.

Balance and Proprioception:

When the athlete demonstrates satisfactory lower extremity strength and control, she may initiate balance and proprioceptive training. She can begin with small range volleyball passes to self or other, and setting at a wall in tandem or single leg stance to improve neuromuscular control with sport-specific movements.

TABLE 1a. Rehabilitation Protocol for Phase 1 and 2

	Phase 1	Phase 2
Optimal Time Frame	0-6 weeks	6-12 weeks
Criteria to Progress	<ul style="list-style-type: none"> · Achieve full extension · Achieve flexion >130 degrees · Patellar mobility 3/6 in all planes · Trace to no suprapatellar effusion · Normal gait mechanics · Ready to initiate SL strengthening 	<ul style="list-style-type: none"> · Quadriceps LSI >65% by 8 weeks and >80% by end of phase · Hip Abductor LSI >80% · Hamstring LSI >70/80% (depending on graft site or concomitant procedures) · Good neuromuscular control with 60-second timed step-down test · Ready to initiate plyometrics
Exercise Recommendations	<ul style="list-style-type: none"> · Quadriceps, hamstring, and gluteal progressive strengthening · DL to SL balance and proprioceptive drills · Lumbopelvic/core stabilization exercises · Rotator cuff and periscapular strengthening 	<ul style="list-style-type: none"> · Progressive resisted SL strengthening exercises · Progress SL balance exercises to simple/complex SL perturbation training with volleyball-specific techniques · Progress rotator cuff and periscapular strengthening
Cardiovascular Recommendations	<ul style="list-style-type: none"> · Stationary bike 20-30 minutes, with minimal to no resistance · Upper body ergometer · Airdyne® bike with arms only 	<ul style="list-style-type: none"> · Stationary bike 30-45 minutes, with moderate resistance · Elliptical beginning at 8 weeks
Pool Program	<ul style="list-style-type: none"> · Gait training at 4 weeks or once incisions healed 	<ul style="list-style-type: none"> · Kick board with straight leg kicking · Aqua jogging 10-20 minutes

(DL, double leg; SL, single leg; LSI, limb symmetry index)

Lumbopelvic/Core Strengthening:

Specific tasks such as hitting, serving, cutting and pivoting require rotational power and control. Transverse plane strength training is required for the volleyball athlete to perform these skills. Acceptable Phase 1 exercises include tall plank, dead bug, diagonal crunch, seated side-to-side twist with overhead press and mini squat with unilateral row by side.

Rotator Cuff and Periscapular Strengthening:

Maintaining shoulder strength and periscapular control is essential for volleyball

athletes when not participating in overhead activities early post-operatively. Recommended exercises for Phase 1 include prone T, Y and horizontal abduction with external rotation starting off a treatment plinth and progressing over a Swiss ball. Resisted band exercises can include shoulder internal and external rotation at 90 degrees of abduction, shoulder PNF D1 and D2 diagonals, standing rows, horizontal abduction and a W. Bicep curls, triceps pull downs, dynamic hug and standing scaption will maintain strength of the athlete's shoulder girdle.

Criteria to Progress to Phase 2: See Table 1a.

PHASE 2: STRENGTHENING

The athlete may progress to Phase 2 once all criteria from Phase 1 is met. The focus for Phase 2 is building strength and addressing neuromuscular and motor control deficits. For the overhead volleyball athlete, a continued emphasis should be placed on shoulder girdle strength progressions in both single and double leg postures to correspond with serving, hitting and blocking. Throughout lower extremity activities, integration of rotational trunk stability will help build the appropriate control for powerful serves, hits and jump-landing tasks.

Suggested Rehabilitation Program for Phase 2:

Balance and Proprioception:

Balance exercises should progress to single leg on dynamic surfaces. The athlete can continue volleyball-specific tasks such as setting at wall, passing and hitting in single leg postures to improve dual-tasking. Tosses to the athlete for passes and hits can progress from predictable to random. Double leg squats on a BOSU® with slow eccentric control and quick concentric quad tightening will prepare the athlete for blocking at the net.

Lumbopelvic/Core Strengthening:

Transverse plane strength training should be progressed from Phase 1 to build core stability, strength and coordination between limbs. Adding side planks with rotations, modified side plank with clamshell, bird-dog with knee-elbow touch, and mountain climbers are appropriate for this phase. Single leg RDL with overhead dumbbell press, reverse lunge with weighted twist, standing chop, reverse chop, and medicine ball throw/catch to a rebounder combines neuromuscular training with core stability to prepare the volleyball athlete for the rotational tasks of hitting and serving.

Rotator Cuff and Periscapular Strengthening to Prepare for Serving, Hitting and Blocking:

Upper extremity strengthening should be performed at least 2-3 times a week to build overhead strength required for serving, hitting and blocking. Exercises from Phase 1 are continued. Shoulder PNF D1 and D2 diagonals and shoulder internal and external rotation at 90 degrees abduction may be progressed to single leg postures cueing for appropriate knee posture in the sagittal and frontal plane should be integrated. External cues, such as cones, can guide the athlete in safe

and onto unstable surfaces. The clinician can add alternating isometrics to the athlete's upper extremity towards end range motions with isometric holds. Bilateral bicep curls with weighted overhead press and band-resisted field goals at a wall will promote the movement of blocking at the net. Integration of closed chain shoulder girdle strengthening such as push-up plus, alternating shoulder taps, or push-ups can begin plantigrade and progress towards the ground.

Criteria to Progress to Phase 3: See Table 1a.

PHASE 3: PLYOMETRIC PHASE

Strength and proprioception training continue during this phase with an emphasis on challenging the athlete in complicated dual-task activities. Adding external perturbations, such as random Swiss ball taps along the athlete's trunk and leg, in single leg postures while performing passing or hitting movements will prepare the athlete for unpredictable contact with players.

Plyometrics are introduced during this phase with close monitoring of signs and symptoms of knee joint effusion or pain. Begin with simple double leg plyometrics advancing to single leg and more complex drills. Plyometrics should be progressed gradually with strong guidance on proper landing techniques, instructing appropriate hip and knee flexion to dissipate tibiofemoral joint forces and optimize shock attenuation. Controlling knee valgum during single leg plyometrics is important for the volleyball athlete who performs repetitive jump-landing tasks throughout play. Use of mirror cues or video can assist the athlete early-on to visualize their knee position and make appropriate corrections. Once double and single leg plyometrics are achieved the athlete can be challenged by advancing speed, direction and distance. When the athlete displays appropriate single limb control during plyometric training, no adverse joint signs, and at least 80% on quadriceps limb symmetry index (LSI), a return to jogging progression program may begin.

Once the athlete completes the return to jogging program, volleyball-specific conditioning drills start. This included linear change in direction drills focusing on proper deceleration mechanics while increasing speed, distance and duration. Lateral change in direction drills prepare the volleyball athlete to move side-to-side on the court. Early directional changes within a controlled environment.

Late in this phase, the athlete can initiate restricted sport-specific activities to familiarize themselves with basic volleyball skills. The athlete can begin passing to a target, stand serving to a target (no jump), and hitting to a target (without approach or jump) to reintroduce volleyball specific movements and improve coordination and accuracy. Performing a blocking movement, without side stepping or jumping, in a squat to heel-raise pattern prepares the athlete for the explosive jumping movement introduced in later phases. A setter can set to a wall with taped-on targets, progressing to setting to planned targets at increased distances to prepare the athlete to set to players on the court or over the net.

It is very important during this phase to communicate specific activity restrictions to the coach, athletic trainer, and parents. Although volleyball is considered a non-contact sport with a net dividing opposing teams, accidental contact in game can occur between teammates or with the opposing team at the net. If unfamiliar with volleyball, clinicians should use extreme caution when clearing an athlete to participate in practice during Phase 3.

Suggested Rehabilitation Program for Phase 3:

Strength:

Strength is focused in single leg postures to address deficits identified during LSI testing. Appropriate functional strength exercises in this phase include rear-foot lunge on slide-board, lateral lunge on slide-board, and rear-foot elevated split-squat with medicine ball press-outs. A split-squat can be progressed onto an unstable surface (BOSU® or tiltboard) with medicine ball rotation away from the front limb to control dynamic knee valgum. Single leg deadlift with resisted row or overhead press, as well as single leg bridge on medicine ball can improve hamstring strength and hamstring-to-quad ratio. Higher-level collegiate and elite level volleyball athletes may begin to incorporate barbell lifts with front squats, split squats and trap bar deadlifts. Communication with an athlete's strength and conditioning coach is imperative throughout this phase to articulate weight lifting and conditioning restrictions.

Lumbopelvic/Core Strengthening:

Incorporate the upper extremity to reproduce the power and explosiveness required for serving, hitting and blocking. Recommendations include side plank with unilateral row, side plank with

unilateral dumbbell external rotation, half-kneeling chops and medicine ball power slams.

Plyometric Exercises:

Plyometrics can be initiated on a Shuttle Press machine to gradually re-introduce impact load in double limb then single limb. Emphasis on proper alignment to minimize knee valgus should be cued. Standing double limb body weight jumps can begin in-place with forward bound, jump down from a small box, and jump up onto a small box focusing on eccentric quad control and appropriate knee flexion when landing. As the athlete's confidence in their limb and neuromuscular control improves, they may initiate traditional box jumps, 90-degree jumps, 180-degree jumps, depth jumps and forward jump off box with vertical jump. Single limb plyometrics progress by increasing height, deceleration control off a step and increasing distance. Once single limb control improves, lateral hops, bounds and leaps can be initiated.

Return to Running Progression:

See Table 2. Return to jogging progression should be completed on level and predictable surfaces at least one minute slower than pre-operative pace per mile. During and after each level, monitor for adverse joint responses such as effusion or pain. To progress to the next level, the athlete must be symptom-free. If symptoms are experienced, work backwards in the progression until pain-free. An athlete may have to repeat a level several times before progressing.

Table 2. Return to Jogging Progression

<i>Day</i>	<i>Walk to Jog Ratio (min)</i>	<i>Total Time (min)</i>
1	4:1	20
2	Off	Off
3	3:2	20
4	Off	Off
5	2:3	20
6	Off	Off
7	1:4	20
8	Off	Off
9	1:5	25
10	Off	Off
11	1:6	30

Special Considerations with Plyometrics:

At the beginning of Phase 3, plyometrics should not be performed on consecutive days. This will minimize adverse joint reactions with introduction

to impact activities. As the athlete progresses through Phase 3, as long as no increased symptoms, the volume of impact may gradually increase and consecutive days are allowed. The clinician must specifically define the athlete's program with repetitions, frequency and duration to prepare the athlete for the demands of volleyball. Please refer to Table 1b.

Cardiovascular Training:

In the later stages of Phase 3, the athlete can initiate volleyball-specific cardiovascular training. Forward and backward pedaling, lateral shuffles and shorter-distance speed work are appropriate.

Sport-Specific Activity:

The athlete may increase their participation in practice under strict supervision with passing and setting drills. They may perform blocking, hitting and serving to targets without directional changes, approaches or jumping. The athlete is not yet cleared to participate in drills involving change of direction or contact.

Functional Movements Assessment/Return to Sport Testing:

In Phase 3, testing becomes more extensive. Every 4-6 weeks, limb symmetry strength testing is performed to assess strength of both limbs working towards limb symmetry. Neuromuscular control tests include the timed step-down test, timed lateral leap and catch test and single leg hop tests.

The timed step-down test is a 60-second test where the athlete performs continuous single-leg squats on a step with hands on hips. The step height is adjusted to achieve 60-70 degrees of knee flexion when their heel taps the ground, to the beat of an 80 beats per minute (bpm) metronome. The timed lateral leap and catch test is a 60-second test where the athlete continuously jumps in a lateral direction from one foot to the other at a distance 60% of the athlete's body height, keeping with a 40-bpm metronome. The single-leg hop tests include single leg hop for distance, triple hop for distance, cross-over hop for distance and the timed 6-meter hop. The distance traveled is measured and compared to the non-operative limb, with assessment of limb quality upon landing^{30,38}. These tests should be performed every 4-6 weeks with strength testing to assess the athlete's progress and provide motivation to return towards sport.

Criteria to Progress to Phase 4: Recommendations to progress to Phase 4 include quadriceps LSI >90%, hip abduction LSI >90%, and hamstring LSI >80-90%(depending on graft site or concomitant

procedure). The single leg lateral step-down test, the timed lateral leap and catch test, and single leg hop tests will assess the athlete's neuromuscular control and endurance. The athlete must achieve >80% LSI for all hop tests to progress to Phase 4. It is critical for the athlete to demonstrate good neuromuscular control with these tests. A clinician should not progress an athlete if poor mechanics are observed despite a >80% LSI score. The athlete should be able to continuously run 20-30 minutes without increased pain or effusion.

Prior to initiating cutting and pivoting activities in Phase 4, the athlete must display efficient and controlled acceleration and deceleration movements throughout linear and lateral movements. If the athlete does not meet these criteria, the clinician must identify impairments deficits to be addressed with a customized treatment plan.

PHASE 4: CUTTING, PIVOTING, SKILL DEVELOPMENT

Phase 4 will continue functional strength, but with an increased emphasis on complex plyometrics, agility and conditioning drills. The athlete will begin cutting, pivoting and changing of direction drills. To challenge the athlete and prepare them for play, speed, direction and resistance can be adjusted. Single limb plyometrics should become more difficult by increasing the speed, volume and direction. Conditioning drills should include quick change in direction and forward and back pedaling to meet the game-like demands of volleyball. Non-contact volleyball drills are performed with close observation of movement between limbs during passing, setting, hitting, serving and digging activities.

Suggested Rehabilitation Program for Phase 4

Strength Exercises:

Communication with a strength and conditioning specialist is recommended throughout this stage. College and elite level athletes may have preseason testing requirements that should be known and discussed for the physical therapist to develop an appropriate program to meet the athlete's testing goals.

TABLE 1b. Rehabilitation Protocol for Phase 3, 4, and 5

	Phase 3	Phase 4	Phase 5
Optimal Time Frame	12-20 weeks	5-7 months	7-9+ months
Criteria to Progress	<ul style="list-style-type: none"> · Quadriceps LSI >90% · Hip abductor LSI >90% · Hamstring LSI >80/90% (depending on graft site or concomitant procedure) · Good neuromuscular control with 60-second timed step-down test · Good landing mechanics with 60-second timed lateral leap and catch · Good landings mechanics with single leg hop cluster (hop for distance, triple hop, crossover hop, 6m timed) >80% of uninvolved limb · Complete return to jogging progression · Optimize volleyball-specific motor control drills 	<ul style="list-style-type: none"> · Quadriceps LSI >95% · Hip abductor LSI >95% · Hamstring LSI >95% · Good neuromuscular control with 60-second timed step-down test · Good landing mechanics with 60-second timed lateral leap and catch · Good landings mechanics with single-leg hop cluster (hop for distance, triple hop, crossover hop, 6m timed) >90% of uninvolved limb · Good landing mechanics with Landing Error Scoring System (LESS) goal < 5^{36,37} · Complete longer runs 20-30 minutes · Good acceleration, deceleration, change of direction and jump-landing control · Ready to initiate controlled contact on the court · Ready to return to reduced volleyball practice 	<ul style="list-style-type: none"> · Quadriceps LSI >95% · Hip abductor LSI >95% · Hamstring LSI >95% · Excellent neuromuscular control with 60-second timed step-down test · Excellent landing mechanics with 60-second timed lateral leap and catch · Excellent landings mechanics with single-leg hop cluster (hop for distance, triple hop, crossover hop, 6m timed) >95% of uninvolved limb · Excellent landing mechanics with Landing Error Scoring System (LESS) < 5^{36,37} · Excellent acceleration, deceleration, change of direction and jump-landing control · Comfortable with all non-contact and controlled contact drills · Participated in reduced volleyball practice, completing final preparation for return to full contact volleyball
Exercise Recommendations	<ul style="list-style-type: none"> · Continue with progressive resisted strengthening from Phase 2 · Maintain ROM - no loss of extension, no increased effusion · Advance plyometrics from DL to SL, from simple to complex · Advance SL perturbation training · Linear change in direction drills · Lateral change in direction drills · Volleyball-specific drills: passing to target, standing serving to target, hitting ball 	<ul style="list-style-type: none"> · Running drills (straight line on court, change in speed, change in direction) · Agility running drills (Figure 8, Zig-Zag, M-drill, T-drill, X-Lane drill) · Rotational control drills · Volleyball-specific drills (non-contact drills only): passing/digging, setting to players, hitting with approach, serving (stand and jump), blocking at net with side step, receiving ball, start of controlled diving 	<ul style="list-style-type: none"> · Initiate controlled contact volleyball-specific drills: contact drills, net drills, hitting drills, receiving drills, diving drills (controlled to random in practice/play), serving drills (ground to jump serve) · Initiate position specific training · Scrimmage/ drills/play 3 on 3, then 6 on 6 · See Table 3: Volleyball Skill Progressions

	without approach or jump, blocking without side step or jump, setting to wall or targets	· See Table 3: Volleyball Skill Progressions	
Cardiovascular Recommendations	· Volleyball-specific cardiovascular training · Longer runs (20-30 minutes in duration)	· Interval Training · Tempo Runs · Fartleks · Shuttle Runs	· Same as Phase 4
Pool Program	· Water jogging	· Water jogging · Swimming can be used for non-impact cardiovascular training	· Swimming can be used for non-impact cardiovascular training

(DL, double leg; SL, single leg; LSI, limb symmetry index)

Table 3. Volleyball Skill Progression

Activity	Level Description	Examples	Phase
Running and Agility Drills	Level 1: Predictable pattern of movement, shorter court distance, slower speed	Warm-up: jog from serving line to net and back 50-75% speed to 3-meter line: forward/back pedal, side shuffles, forward sprints with turns at line	4
	Level 2: Predictable pattern of movement, longer court distance, quicker speed	Warm-up: jog full court and back 75-100% speed to half court: side shuffles, forward/back pedal, forward sprint with turns at line Line touches at full speed: 3-meter line, net, opposing 3-meter line, far end of court	4
	Level 3: Change of direction pattern of movement, agility/cone drills	50-100% speed Figure 8, Zig-Zag Drill, M-Drill, T-Drill, and X-Lane Drill	4
Blocking Drills	Level 1: Side step to block along net	Without jump	4
	Level 2: Side step to block along net	With jump to height of net	4
	Level 3: Side step to block along net	With full jump above height of net	4
	Level 4: Advanced blocking with team drills	Side step and full block performed with teammate Side step and full block performed with hitter on opposite side of net	5
	Level 5: Advanced blocking in scrimmage/game	Blocking in scrimmage Blocking in game	5
Hitting Drills	Level 1: Hitting approach at 50% effort	Footwork no ball Addition of ball set to player	4
	Level 2: Hitting approach at 75-100% effort	Footwork no ball Addition of ball set to player	4
	Level 3: Hitting approach at 75-100% effort with target hitting	10-20 hits down line 10-20 hits cross court 10-20 roll shots 5-10 tips/dumps	4
	Level 4: Advanced hitting in team drills	Hitting approach at full speed for all practice drills	5

	Level 5: Advanced hitting drills in scrimmage/game	Hitting approach at full speed for team scrimmage	5
		Hitting approach at full speed in games	
Ball Passing and Digging Drills	Level 1: 50-75% effort	Peppering goal 3-5min	4
		Roll shot	
		Forearm passes: serve receive, defense, passing drills	
		Setters: set to outside hitter	
	Level 2: 75%-100% effort	Peppering goal 5-10min	4
		Roll shots	
		Forearm passes: serve receive, defense, passing drills	
		Begin controlled pass to dive drills	
		Overhead receive: defense, passing drills	
		Setters: sets to all hitters on court	
Level 3: Full effort with team drills	Digging, passing, and/or setting in practice	4	
Level 4: Full effort in scrimmage/game	Digging, passing, and/or setting in scrimmage	5	
	Digging, passing, and/or setting in games		
Serving Drills	Level 1: Standing float serves	Hit over net	4
		Hit to specific target on opposite side of court	
	Level 2: Jump float serves	Hit over net	4
		Hit to specific target on opposite side of court	
	Level 3: Jump serve with top spin serve at 75% effort	Hit over net	4
		Hit to specific target on opposite side of court	
	Level 4: Jump serve with top spin at full effort in practice drills	Hit over net	5
		Hit to specific target on opposite side of court	
	Level 5: Advanced serving in scrimmage/game	Hit during scrimmage	5
		Hit during game	

Sport-Specific Activity:

Running drills on a court should include straight line run, directional changes and speed adjustments. Agility drills become more complex to mirror game-like play with recommendation of Figure-8, Zig-Zag, M-Drills, T-Drills or X-Lane drills. Non-contact volleyball-specific drills appropriate for this phase including passing/digging, setting to players, hitting with approach, serving, blocking at net with side step, receiving balls and start of controlled diving drills.

Cardiovascular Considerations:

A volleyball game can range from three to five sets depending on score. It is essential the athlete is conditioned for quick movements on the court, but also has the endurance to play in all five sets. High intensity interval training, tempo runs, fartleks and shuttle runs should be included. Sprinting at increased intensities on the court with line touches from half to full court will prepare the athlete for quick directional changes to receive a ball in play. The athlete should also continuously run 20-30 minutes at their pre-injury speed to maintain endurance.

Criteria to Progress to Phase 5: Recommendations to progress to Phase 5 include quadriceps LSI >95%, hip abduction LSI >95% and hamstring LSI >95%. All single-leg hop tests >90% with excellent take-off and landings. All neuromuscular control tests detailed above with excellent control. Due to the nature of volleyball with horizontal and vertical jumping, the Landing Error Scoring System (LESS) should be considered to assess jump-landings tasks. The athlete stands on a 30-cm high box. A landing area at a distance half the athlete's body height from the box is marked by a line. The athlete jumps forwards landing past this line then immediately jumps up at maximal height. A scoring sheet is used to score the athlete based on 10 parts assessing frontal and sagittal plane motions^{36,37}. Padua et al suggested young-athletes with score >5 may be at higher risk of sustaining ACL injuries³⁷.

The athlete must demonstrate proper acceleration, deceleration, cutting and pivoting movements off both the affected and unaffected limb with control and full confidence. A psychological return to readiness scale is recommended at this stage, such as the ACL-RSL scale to identify psychological barriers that may need to be addressed before initiating full play. The scale should be performed prior to the athlete completing strength, motor control, and hop testing

to avoid bias from performance on physical tests. The volleyball athlete must demonstrate eagerness to begin controlled contact and modified participation in supervised practice.

PHASE 5: CONTROLLED CONTACT/ RETURN TO PLAY

Phase 5 is the final stage to prepare the athlete for full sport. Functional strengthening continues, but the emphasis shifts to plyometrics, agility, conditioning and jump-landing activities specific for volleyball. Controlled contact is introduced during running, cutting and pivoting movements on the court. Position-specific training is heavily emphasized. The athlete participates in reduced volleyball practice, completing final preparation to return to full contact volleyball. The athlete can begin with full team practice, then scrimmaging with team before playing in a game. Recommend the athlete begin playing in one to two sets, working up towards a full three to five sets as long as no adverse reactions reported and the athlete is confident in her ability to play.

Suggested Rehabilitation Program for Phase 5

Strength Exercises:

In Phase 5, a functional strengthening program should continue. Collaboration with the strength and conditioning specialist should occur to coordinate the athlete's program. College and elite level athletes can perform their strength program with their teams. Olympic lifts such as power cleans, the dumbbell snatch and the push jerk can be integrated to advance power and explosiveness required for hitting, blocking and serving. It is essential the entire rehabilitation team is in communication and in agreement about the athlete's plan during this phase to avoid conflict or confusion with the athlete's return-to-play status and timeline.

Sport-Specific Activity:

Controlled contact with volleyball-specific drills is appropriate at this phase. Blocking drills at the net can go towards full speed. Blocking can be coordinated with a teammate on the same side of the net, then progressed to add a hitter on the opposing side to react to. The athlete should hit with their full approach during practice drills, progressing to hitting in scrimmages, then full game play. The serve is performed at full effort with the athlete transitioning into play once the serve goes over the net. The athlete participates in various receiving and diving drills, first controlled then

progressed to random in practice and eventually during game-like scenarios. The athlete can participate in court drills and scrimmages first 3-on-3 prior to initiating 6-on-6. This progression allows the athlete to become more confident in their skills and identify limitations in performance that need to be addressed.

Criteria to Discharge to Return to Volleyball

The volleyball athlete must maintain all Phase 4 criteria to progress and demonstrates excellent neuromuscular control with all functional movement tests. During all volleyball-specific activities the athlete must display psychological readiness and confidence. A score of >90 on the ACL-RSI questionnaire is recommended to demonstrate psychological readiness to return to full sport. The athlete must illustrate excellent bilateral neuromuscular control with position-specific training including serving, passing, setting, hitting, digging and diving, and be able to receive the ball in game-like scenarios.

SUMMARY

Women's indoor volleyball participation has increased from youth club to professional leagues¹. It has developed into the number one team sport for girls in high school and collegiate levels². With higher participation comes increased risk for volleyball-specific injuries. ACL injuries most frequently occur when landing from a jump or in the front three positions at the net^{1,2,10,14}. Female volleyball athletes are at a higher incidence of ACL injury compared to their male counterparts¹⁴. Although a rising injury rate in volleyball players, there is limited research and guidance on returning a volleyball athlete to sport.

Several studies have demonstrated female athletes are at increased risk for ACL injuries due to cutting and landing biomechanical differences compared to males¹². These neuromuscular risk factors have been shown to be modifiable through neuromuscular training²⁰. This becomes an essential component of post-operative ACL rehabilitation in the volleyball athlete who has to repetitively jump, land and pivot on the court. In volleyball, Takahashi et al found the number of non-contact ACL injuries was significantly higher than rates of contact injuries¹⁶. This suggests emphasis on jump-landing training is critical. Further research on neuromuscular training for jump-landing techniques in injury prevention programs for the volleyball athlete should be

considered to look at changes in ACL injury rate and differences between females and males.

Although regaining lower body strength, proprioception and neuromuscular control is essential throughout post-operative ACL rehabilitation, upper extremity strength and lumbopelvic control drills must also be initiated early for the volleyball athlete. This will ensure the athlete has the appropriate rotatory control and power to hit, serve and block in later stages. Due to the repetitive nature of jump-landing tasks and directional changes to receive balls on the court, the clinician must keep a close eye on the athlete's neuromuscular control and quality of movement during single limb strengthening, plyometrics, agilities and sport-specific movements. The athlete should be reintroduced gradually to their sport and meet the criteria-based goals of each phase to progress.

For successful RTS, regular communication must occur between the athlete, physician, physical therapist, coach, strength and conditioning team, athletic trainer and parents. This will ensure a smooth transition from rehabilitation to full return to play on the court. This clinical commentary should serve as a guide for a physical therapist working with a female volleyball athlete post-operative ACL reconstruction. Further research is required to determine modifiable risk factors that can be addressed in regular season training to reduce injury risk and to improve upon rehabilitation guidelines after ACL reconstruction for the female volleyball athlete.

Conflict of Interest Statement

The author reports no conflict of interest with the contents of this manuscript.

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