Are There Speed Limits in Rehabilitation?

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During the course of rehabilitation of a patient, I often wonder if there are speed limits to our rehabilitation program. This dilemma usually occurs when a patient is recovering exceedingly fast, making me wonder if we are progressing too quickly and violating the soft tissue healing constraints. In the specific case of patients who have undergone ACL reconstruction, the primary healing constraints we should be concerned about are revascularization of the graft, graft remodeling, graft incorporation, and regeneration of graft strength. With these patients, I'm mainly concerned about the consequences of a fast or accelerated rehabilitation process. Does the accelerated rehabilitation program lead to increased laxity, a higher rate of graft failure, articular cartilage damage, or early degenerative changes of the joint? By returning someone back to sports quickly, are we placing the patient at risk for other problems now or years later? Is our ultimate goal of rehabilitation to return someone to sports as quickly as possible or to return them when it's safe for them? The case report by Roi et al, along with the invited commentaries by Drs Fithian and Shelbourne, published in this month's *Journal* raise many issues we must all ponder when considering the speed of the rehabilitation process.

Can the accelerated rehabilitation philosophy apply to all patients or is it a better fit for young athletes who undergo ACL reconstruction? We all realize—or soon will if we haven't already—that the older we get the longer it takes to recover from injuries or surgeries. Thus, maybe the older recreational athlete isn't the right candidate for accelerated ACL rehabilitation. Do other injuries to the knee preclude the patient from participating in accelerated rehabilitation? Injuries to the meniscus or collateral ligaments, especially the lateral collateral ligament, may require more time to heal. Injuries to the articular cartilage may also require a slower rehabilitation process and, in such cases, some of the accelerated rehabilitation principles may be contraindicated. Furthermore, the healing rate may be affected by age, genetics, nutrition, concomitant injuries, and the patient's unique healing characteristics. To adjust for these individual differences some authors have suggested a rehabilitation program based on an evaluation-based protocol compared to a time-based protocol.[10]

Do these basic considerations related to accelerated rehabilitation principles also apply to patients with other types of pathologies? When is it safe for the patient who has undergone rotator cuff repair to begin an aggressive strengthening program? The same question may apply to the thrower who has undergone an ulnar collateral ligament reconstruction of the elbow. When is it safe to begin a throwing program or return to competitive pitching? These are questions clinicians struggle with daily.

The fact is, injuries to the ACL rarely occur in isolation.[5,9] Usually there is injury to the medial collateral ligament and to the meniscus.[8] But not all injuries are visible. One of those hidden lesions to the knee joint are bone bruises. Several authors[7,12] have reported that over 80% of patients who sustain an acute ACL injury exhibit a bone bruise on MRI. Johnson et al[7] have reported that patients with a bone bruise who underwent ACL reconstruction required a longer period to reduce effusion and pain, and to return muscle function. Additionally, the effects of the bone bruise may not be seen for years after the initial injury. The result may be articular cartilage lesions and the development of early knee

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osteoarthritis. This type of knee injury may alter the overall knee joint function and affect the homeostasis of the knee.[3] The decisions we make as rehabilitation specialists may have significant effects on the metabolic activity of the knee joint following the injury and in returning the joint to normal homeostasis.

The traditional basic science of graft healing, regeneration of graft strength, and revascularization has been recently challenged by clinical studies that contradict or ignore the previously established guidelines. Basic science studies would indicate that a soft tissue graft heals differently than a bone-tendon-bone graft, and that it takes months for a graft to revascularize and much longer to regenerate most of its tensile strength. If we accelerate the rehabilitation, are we exceeding the speed limits of the basic science of tissue healing? However, controversy exists concerning the process and rate of graft revascularization. Some investigators have reported revascularization of the graft in 8 to 10 weeks, while others have reported 6 months.[1,2,4]

How do we judge if we as rehabilitation specialists did a good job? How do we measure if we accomplished our rehabilitation goals? Some may say it is how fast the patient returns to sports, others may say it is an outcome measurement tool, like the IKDC or Cincinnati Sports Medicine Knee Form.[6,11] I offer to you that it is a measure of longevity, productivity, and patient satisfaction. These measures are not to be taken only at the time of discharge or medical release to return to play, but years after discharge from the rehabilitation program. In my mind, the ultimate goal is a healthy, asymptomatic knee 5 to 10 years after ACL reconstruction, not just at 6 months. By accelerating the rehab are we adversely affecting this long-term outcome? Are we exceeding the speed limits?

Speeding through the rehabilitation program may have more risks than benefits. When we speed in our automobiles we may be caught by the law and pay a fine. If we speed in the rehabilitation program, we may have to suffer more significant consequences—patients with unsatisfactory knee function for the rest of their lives. These risks must be evaluated for each patient and should not be applied to all patients without careful consideration of the consequences.

We need posted speed limits in rehabilitation. The problem is, we are not certain what these speed limits are.

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Recent advances in the rehabilitation of isolated and combined anterior cruciate ligament injuries

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A scientifically based and well-designed rehabilitation program plays a vital role in the functional outcome of the anterior cruciate ligament (ACL)-reconstructed knee patient. Howe et al [1] reported improved outcomes with formal supervised rehabilitation compared with individuals who did not receive supervised rehabilitation. These improved outcomes included greater motion, improved muscular strength, and enhanced earlier function.

Rehabilitation following ACL injury/surgery has undergone an evolution in the past decade. Specifically, the rehabilitation regimen has significantly changed since the late 1980s. In the past, several authors [2–5] have recommended 6–8 weeks of immobilization, and 8–12 weeks of crutch use. Others [2,3,6–10] have recommended the avoidance of early isolated quadriceps contractions to assist in protecting the reconstructed knee. Furthermore, a return to sporting activities was not permitted until 9–12 months postsurgery [2,4,7].

Many complications reported in the literature following ACL reconstructive surgery, such as joint stiffness, arthrofibrosis, quadriceps weakness, extensor mechanism dysfunction, and/or donor site pain, may have been the secondary result of delayed motion (immobilization) and, in general, a more conservative rehabilitation approach. [4,8,11–19].

Currently, the rehabilitation programs employed following ACL reconstruction are more aggressive than those utilized prior to 1988. The foundation employed today emphasizes immediate motion [20–26], full passive knee extension [22,26–28], immediate weight-bearing [18,26,29], and functional exercises to improve the patient's overall outcome [26,30,31]. This trend toward aggressive rehabilitation of the ACL reconstructed knee patient is partly the result of the improved outcomes documented with accelerated rehabilitation compared with more conservative programs.

Presently, we employ two different rehabilitation programs for isolated ACL reconstructed patients. The accelerated rehabilitation approach is utilized for the young, athletic patient, whereas the older recreational patient would follow a slower program, referred to as the regular rehab program. The main difference between the two programs is the rate of progression through the various phases of rehabilitation and the period of time necessary prior to running and sports.

In 1990, Shelbourne and Nitz [27] reported improved clinical outcomes in patients who followed an accelerated approach compared with a conservative rehabilitation approach. The patients who followed the accelerated approach exhibited better strength and range-of-motion (ROM) and fewer complications, such as arthrofibrosis, laxity, and failures. The accelerated group, furthermore, had less patellofemoral complaints and an earlier return to sports.

In this article, we will discuss the principles of ACL rehabilitation that we follow, variations in rehabilitation based on graft type and concomitant injury/surgery, and the special rehabilitation considerations for the female athlete. We will attempt to provide a scientific basis for the rationale of these specific programs.

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Priniciples of ACL rehabilitation

First, we will briefly describe our accelerated rehabilitation program following ACL reconstruction using an ipsilateral patellar tendon autograft (Box 1). Specific guidelines and protocols for ACL reconstruction, using various graft sources and concomitant procedures, will be discussed later.

We begin our rehabilitation program, whenever possible, preoperatively. Common preoperative goals are to reduce pain, inflammation, and swelling, restore normal range-of-motion, normalize gait, and prevent muscle atrophy. Patient education is another critical aspect of preoperative rehabilitation to prepare and educate the patient on both the surgical procedure and the we rehabilitation.

Postoperative rehabilitation begins immediately following surgery with immediate motion and weight-bearing activities. Full passive knee extension is emphasized with a gradual restoration of flexion range-of-motion. Weight-bearing is allowed as tolerated immediately following surgery with a progression to full weight-bearing without crutches by 10–14 days. Closed kinetic chain proprioceptive and strengthening exercises are initiated during the first 2 weeks postoperatively. A combination of open kinetic chain and closed kinetic chain exercises are incorporated and progressed as tolerated. Neuromuscular control drills are gradually advanced to include dynamic stabilization and perturbation training (week 2–3), and light plyometric jump training (week 8). Functional activities such as running begins on week 8–10, jumping on week 10–14, cutting on week 12–16, and, finally, a gradual return to athletic competition for running and cutting sports, such as baseball, football, tennis, and soccer at approximately 4–6 months, and, to jumping sports, such as basketball and volleyball, at 6–9 months.

All of our postoperative programs have been designed based on several key principles of ACL rehabilitation that are incorporated to ensure a satisfactory postoperative outcome and to return the athlete to sports as quickly as possible. Each one will be discussed in detail.

Full passive knee extension

One of the most common complications following ACL reconstruction is motion loss, particularly loss of full knee extension. The inability to extend the knee fully results in abnormal joint arthrokinematics and subsequent increases in patellofemoral and tibiofemoral joint contact pressure, inability to contract the quadriceps muscle, and muscular fatigue [32,33].

Box 1. Accelerated rehabilitation following ACL-patellar tendon graft (PTG) reconstruction

Preoperative phase

Goals:
- Diminish inflammation, swelling, and pain
- Restore normal range-of-motion (especially knee extension)
- Restore voluntary muscle activation
- Provide patient education to prepare patient for surgery
- Brace—elastic wrap or knee sleeve to reduce swelling
- Weight-bearing—as tolerated with or without crutches

Exercises:
- Ankle pumps
- Passive knee extension to zero
- Passive knee flexion to tolerance
- Straight leg raises (3-way, flexion, abduction, adduction)
- Quadriceps setting
- Closed kinetic chain exercises: mini squats, lunges, step-ups

Muscle stimulation—electrical muscle stimulation to quadriceps during voluntary quadriceps exercises (4–6 hours per day)

Cryotherapy/elevation—apply ice 20 minutes of every hour, elevate leg with knee in full extension (knee must be above heart)

Patient education—review postoperative rehabilitation program

Review instructional video (optional)

Select appropriate surgical date

Immediate postoperative phase (day 1–day 7)

Goals:
- Restore full passive knee extension
- Diminish joint swelling and pain
- Restore patellar mobility
- Gradually improve knee flexion
- Reestablish quadriceps control
- Restore independent ambulation

Postoperative Day (POD) 1

Brace—EZ Wrap™ (Professional Products, DeFuniak, FL) brace/ Immobilizer applied to knee, locked in full extension during ambulation

Weight-bearing—2 crutches, weight-bearing as tolerated

Exercises:

- Ankle pumps
- Overpressure into full, passive knee extension
- Active and passive knee flexion (90° by day 5)
- Straight leg raises (flexion, abduction, adduction)
- Quadriceps isometric setting
- Hamstring stretches
- Closed kinetic chain exercises: mini squats, weight shifts

Muscle stimulation—use muscle stimulation during active muscle exercises (4–6 hours per day)

Continuous passive motion—as needed, 0° to 45/50° (as tolerated, and as directed by physician)

Ice and evaluation—ice 20 minutes out of every hour, and elevate with knee in full extension

POD 2 to Day 3

Brace—EZ Wrap brace/Immobilizer, locked at zero degrees extension for ambulation and unlocked for sitting, etc., or Protonics Rehab System (PRS) as directed by physician

Weight-bearing—2 crutches, weight-bearing as tolerated

Range-of-motion—remove brace, perform range-of-motion exercises 4 to 6 times a day

Exercises:

- Multi-angle isometrics at 90° and 60° (knee extension)
- Knee extension 90° to 40°
- Overpressure
- Patellar mobilization
- Ankle pumps
- Straight leg raises (3 directions)
- Mini squats and weight shifts
- Standing hamstring curls
- Quadriceps isometric setting

Muscle Stimulation—electrical muscle stimulation to quads (6 hours per day)

Continuous passive motion—0° to 90° as needed

Ice and evaluation—ice 20 minutes out of every hour,and elevate leg with knee in full extension

POD 4 to Day 7

Brace—EZ Wrap brace/Immobilizer, locked at zero° extension for ambulation and unlocked for sitting, etc., or PRS as directed by physician

Weight-bearing—2 crutches, weight-bearing as tolerated

Range-of-motion—remove brace to perform range-of-motion exercises 4 to 6 times per day, knee flexion 90° by day 5, approximately 100° by day 7

Exercises:

- Multi-angle isometrics at 90 and 60 degrees (knee extension)
- Knee extension 90° to 40°
- Overpressure into extension
- Patellar mobilization
- Ankle pumps
- Straight leg raises (3 directions)
- Mini squats and weight shifts
- Standing hamstring curls
- Quadriceps isometric setting
- Proprioception and balance activities

Muscle stimulation—electrical muscle stimulation (continue 6 hours daily)

Continue passive motion—0° to 90° as needed

Ice and elevation—ice 20 minutes of every hour, and elevate leg with knee full extension

Early rehabiliation phase (weeks 2–4)

Criteria to progress to phase 2

- Quad control (ability to perform good quad set and straight leg raises [SLR])
- Full passive knee extension
- Passive range-of-motion (PROM) 0° to 90°
- Good patellar mobility

- Minimal joint effusion
- Independent ambulation

Goals:

Maintain full passive knee extension
Gradually increase knee flexion
Diminish swelling and pain
Muscle training
Restore proprioception
Patellar mobility

Week 2

Brace—discontinue brace or immobilizer at 2 to 3 weeks
Weight-bearing—as tolerated (goal is to discontinue crutches 10 days postop)
Range-of-motion—self-ROM stretching (4–5 times daily), emphasis on maintaining full, passive range-of-motion
KT 2000 Test—(15 lb. anterior-posterior test only)
Exercises

- Muscle stimulation to quadriceps exercises
- Isometric quadriceps sets
- Straight leg raises (4 planes)
- Leg press
- Knee extension 90° to 40°
- Half squats (0° to 40°)
- Weight shifts
- Front and side lunges
- Hamstring curls
- Bicycle
- Proprioception training
- Overpressure into extension
- Passive range-of-motion from 0° to 50°
- Patellar mobilization
- Well leg exercises
- Progressive resistance extension program—start with 1 lb., progress 1 lb. per week

Swelling control—ice, compression, elevation

Week 3

Brace—discontinue
Range-of-motion—continue range-of-motion stretching and overpressure into extension

Exercises:

- Continue all exercises as in week 2
- Passive range-of-motion 0° to 115°
- Bicycle for range-of-motion stimulus and endurance
- Pool walking program (if incision is closed)
- Eccentric quadriceps program 40° to 100° (isotonic only)
- Lateral lunges
- Lateral step-ups
- Front step-ups
- Lateral step-overs (cones)
- Stair-Stepper machine
- Progress proprioception drills, neuromuscular control drills

Controlled ambulation phase (weeks 4–10)

Criteria to Enter Phase 3

Active range-of-motion 0° to 115°
Quadriceps strength 60% > contralateral side (isometric test at 60° knee flexion)
Unchanged KT Test bilateral values (+1 or less)
Minimal to no full-joint effusion
No joint line or patellofemoral pain
Goals:

Restore full knee range-of-motion (0° to 125°)
Improve lower extremity strength
Enhance proprioception, balance, and neuromuscular control
Improve muscular endurance
Restore limb confidence and function
Brace—no immobilizer or brace, may use knee sleeve
Range-of-motion—self-ROM (4–-5 times daily using the other leg to provide ROM), emphasis on maintaining zero° passive extension
KT 2000 Test—(week 4, 20 lb. anterior and posterior test)

Week 4

Exercises:

- Progress isometric strengthening program

- Leg press
- Knee extension 90° to 40°
- Hamstring curls
- Hip abduction and adduction
- Hip flexion and extension
- Lateral step-overs
- Lateral lunges
- Lateral step-ups
- Front step-downs
- Wall squats
- Vertical squats
- Toe calf raises
- Biodex Stability System (balance, squats, etc.)
- Proprioception drills
- Bicycle
- Stair Stepper machine
- Poor program (Backward running, hip and leg exercises)

Week 6

KT 2000 Test—20 and 30 lb. anterior and posterior test

Exercises:

- Continue all exercises
- Poor running (forward) and agility drills
- Balance on tilt boards
- Progress to balance and board throws

Week 8

- KT 2000 Test—20 and 30 lb. anterior and posterior test

  Exercises:

  - Continue all exercises listed in weeks 4 to 6
  - Plyometric leg press
  - Perturbation training
  - Isokinetic exercises (90° to 40°) (120° to 240°/second)
  - Walking program
  - Bicycle for endurance
  - Stair Stepper machine for endurance

Week 10

KT 2000 Test—20 and 30 lb. and Manual Maximum Test

Isokinetic Test—concentric knee extension/flexion at 180° and 300°/second

Exercises:

- Continue all exercises listed in weeks 6, 8, and 10
- Plyometric training drills
- Continue stretching drills

Advanced activity phase (weeks 10–16)

Criteria to enter phase 4

- Active range-of-motion (AROM) 0° to 125° or greater
- Quad strength 79% of contralateral side, knee extension flexor: extensor ratio 70% to 75%
- No change in KT values (comparable with contralateral side, within 2 mm)
- No pain or effusion
- Satisfactory clinical exam
- Satisfactory isokinetic test (values at 180°)

  Quadriceps bilateral comparison 75%

  Hamstrings equal bilateral

  Quadriceps peak torque/body weight

  Hamstrings/quadriceps ratio 66% to 75%
- Hop Test (80% of contralateral leg)
- Subjective knee scoring (modified Noyes System) 80 points or better

  Goals:

  Normalize lower extremity strength

  Enhance muscular power and endurance

  Improve neuromuscular control

  Perform selected sport-specific drills

  Exercises

  Continue all exercises

Return to activity phase (weeks 16–22)

Criteria to enter phase 5

- Full range-of-motion
- Unchanged KT 2000 Test (within 2.5 mm of opposite side)
- Isokinetic test that fulfills criteria
- Quadriceps bilateral comparison (80% or greater)

- Hamstring bilateral comparison (110% or greater)
- Quadriceps torque/body weight ratio (55% or greater)
- Hamstrings/quadriceps ratio (70% or greater)
- Proprioceptive test (100% of contralateral leg)
- Functional test (85% or greater of contralateral side)
- Satisfactory clinical exam
- Subjective knee scoring (modified Noyes System) (90 points or better)

Goals:

Gradual return to full unrestricted sports

Achieve maximal strength and endurance

Normalize neuromuscular control

Progress skill training

Tests—KT 2000, isokinetic, and functional tests before return

Exercises:

- Continue strengthening exercises
- Continue neuromuscular control drills
- Continue plyometrics drills
- Progress running and agility program
- Progress sport-specific training

6-Month follow-up

Isokinetic test

KT 2000 test

Functional test

12-month follow-up

Isokinetic test

KT 2000 test

Functional test

Thus, one of the primary goals of postoperative rehabilitation involves achieving full passive knee extension immediately following surgery.

Cosgarea et al [34] compared the effects of postoperative bracing at various degrees of knee range-of-motion on the incidence of arthrofibrosis following ACL reconstruction. The authors compared the effects of two groups of patients. One group was braced at 45° of knee flexion and waited 1 week prior to beginning range-of-motion exercises and had a 23% incidence of motion complications. The other group was braced at 0° knee extension and initiated range-of-motion exercises immediately following surgery and had a 3% incidence of motion complications. Similarly, several authors have reported that immediate motion is essential to avoid range-of-motion complications [28,34–37], whereas failure to achieve full extension has been associated with poor postoperative results [38,39]. Therefore, we use a drop-lock postoperative knee brace locked at 0° of extension and perform range-of-motion out of the brace immediately following surgery. The locked brace is used while ambulating and sleeping during the first 2–3 weeks after surgery.

Our goal is to achieve at least 0° of knee extension in the first few days postoperatively. Specific exercises utilized include manual passive range-of-motion exercises performed by the rehabilitation specialist, supine hamstring stretches with a wedge under the heel, and gastrocnemius stretching with a towel. Overpressure of 10 lbs. may be used for a low-load, long-duration stretch as needed to achieve full extension (Fig. 1).

A certain amount of controversy exists regarding restoration of full hyperextension. Some authors have reported that restoring full hyperextension does not affect ligamentous stability [40]. For patients with significant hyperextension of the uninvolved extremity, however, we suggest regaining approximately 7° of hyperextension through stretching techniques in the clinic. The remaining hyperextension may be achieved through functional activities. We believe this allows the patient to gain a greater degree of neuromuscular control at the end range of extension and avoids uncontrolled and unexpected hyperextension movements.

Restoration of patellar mobility

The loss of patellar mobility following ACL reconstruction may be caused by various reasons, including excessive scar tissue adhesions along the medial and lateral gutters and harvesting the infrapatellar tendon for reconstruction. The loss of patellar mobility may result in range-of-motion complications and difficulty recruiting quadriceps contraction. Patellar mobilizations are performed by the rehabilitation specialist, and independently by the patient during the home exercise program. Mobilizations are performed in the medial-lateral and superior-inferior direction. Particularly, attention must be paid to superior-inferior patellar mobility for patients with patellar tendon autografts to prevent excessive scar tissue formation and an inferiorly positioned patella.

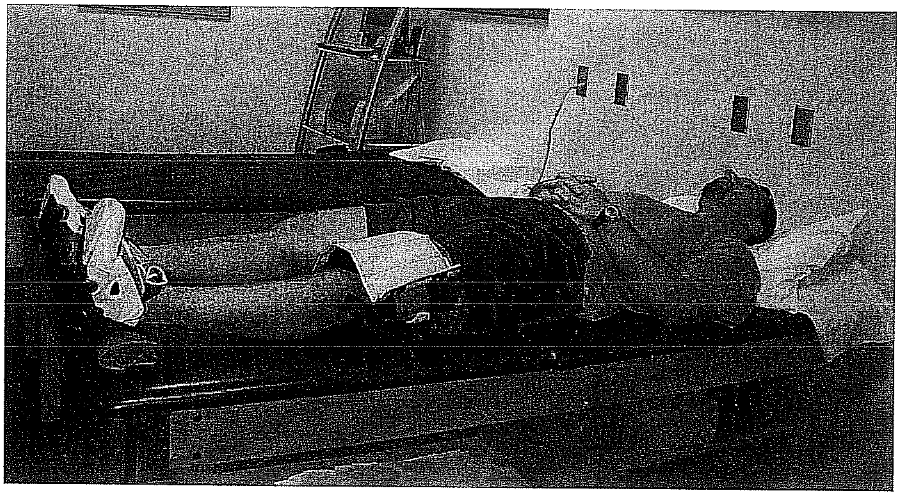

Fig. 1. A Low-load, long-duration stretch used to restore the patient's full passive knee extension. A 10-lb. weight is used for 10–12 minutes, while a bolster is placed under the ankle to create a stretch.

Paulos et al [41] has reported on the loss of patella mobility, referred to as infrapatella contracture syndrome (ICS). This syndrome may lead to significant knee dysfunction.

Reduce postoperative inflammation

Although full passive knee extension and patellar mobility are two of the primary goals during the first week of rehabilitation, controlling postoperative pain, inflammation, and swelling are also imperative immediately following surgery.

Pain may play a role in the inhibition of muscle activity commonly observed following ACL reconstruction. Young et al [42] examined quadriceps activity in the acutely swollen and painful knee. An afferent block by local anesthesia was given intraoperatively during medial meniscectomy. Patients in the control group reported significant postoperative pain and quadriceps inhibition (30% to 76%). By contrast, patients with local anesthesia reported minimal pain and only mild quadriceps inhibition (5% to 31%).

Numerous authors have studied the effect of joint effusion on muscle inhibition. DeAndrade et al [43] reported that joint distention resulted in quadriceps muscle inhibition. A progressive decrease in quadriceps activity was noted as knee distention increased. Spencer et al [44] found a similar decrease in quadriceps activation with joint effusion. The authors reported the threshold for inhibition of the vastus medialis to be approximately 20–30 mL of joint effusion and 50–60 mL for the rectus femoris and vastus lateralis. Mangine et al (unpublished) reported that the most significant muscular inhibition occurred in the vastus medialis oblique. Similar results have been reported within the literature [45–48].

Pain can be reduced passively through the use of cryotherapy and analgesic medication. Passive range-of-motion may also assist in the neuromodulation of pain. Therapeutic modalities such as electrical stimulation may also be used to control pain via the gate control theory [49]. Treatment options for swelling reduction include cryotherapy, high-voltage stimulation, and joint compression through the use of a knee sleeve or compression wrap. A commercial cold device (Fig. 2) providing continuous cold therapy may also be beneficial for the patient.

The speed of progression of weight-bearing status and range-of-motion may also affect pain and swelling in the knee. In general, our patients are allowed to bear weight as tolerated with two crutches and the brace locked into extension immediately following surgery. The brace is worn until voluntary quadriceps control is present. A critical goal of week 2 is training the patient to assume full weight-bearing. This may be facilitated with the use of a force platform (eg, NeuroCom Balance System, NeuroCom International, Clackamas, OR) to measure the amount of body-weight distribution during weight-bearing exercises such as weight shifts and mini squats (Fig. 3). Both crutches are used for the first 7–10 days, progressing to 1 crutch, and finally to full weight-bearing without crutches by 10–14 days. This progression allows the rehabilitation specialist to alter the weight-bearing progression to assure that in-

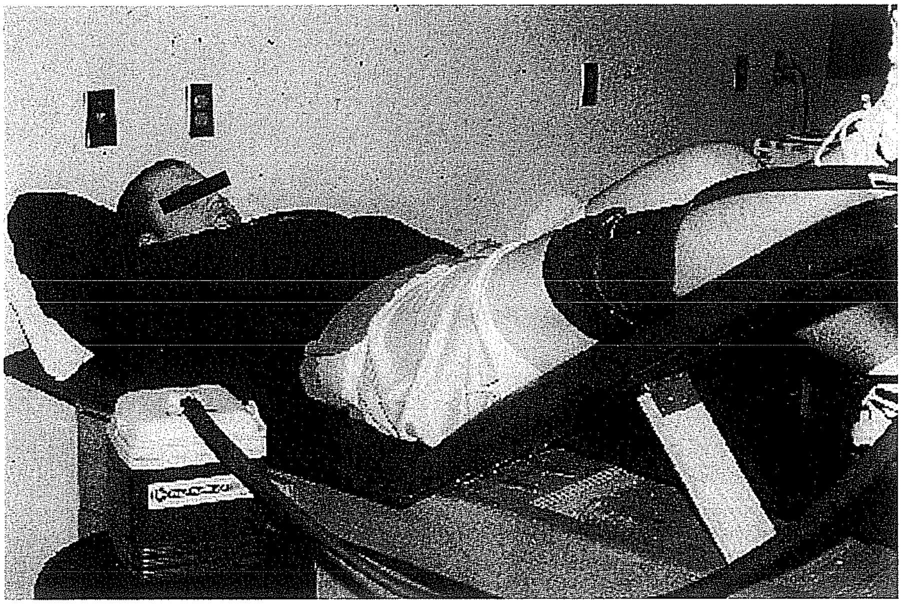

Fig. 2. A commercial cold wrap (eg, Polar Care, Breg Corporation, Vista, CA) is applied to the knee immediately after surgery.

creased pain and swelling does not ensue and retard the rehabilitation process secondary to excessive weight-bearing forces. Also, weight-bearing may be altered if concomitant surgeries are performed (i.e. meniscus, articular cartilage, etc.).

Range is also progressed gradually during week 1 to control postoperative pain and swelling. The rate of progression is based on the patient's unique response to surgery. If substantial effusion exists, range-of-motion is advanced at a slower pace, allowing adequate time for swelling to subside. Generally, by PODs 5–7, the patient should exhibit 0° to 90° of knee range-of-motion, and by days 7° to 10, 0° to 100° of motion. Over the course of the next month as knee pain and swelling subside, flexion range-of-motion may be progressed gradually from 105° in week 2, to 115° in week 3, and to 125° and beyond beginning in week 4.

We believe that the first 2–4 weeks following surgery is a very important time during ACL rehabilitation to control the homeostasis of the knee joint. Pain and swelling control are imperative to regain function within the knee postoperatively. Persistent pain, inflammation, and swelling may result in long-term complications involving range-of-motion, voluntary quadriceps control, and a delaying of the rehabilitation process. The rate of weight-bearing and range-of-motion progression must be altered to each specific patient to allow the knee to calm down and avoid impediment of the rehabilitation program.

Re-establish voluntary quadriceps control

Inhibition of the quadriceps muscle is a common clinical enigma in postoperative ACL reconstruction patients, especially in the presence of pain and effusion during the acute phases of rehabilitation as previously discussed. Electrical muscle stimulation and biofeedback are often incorporated with therapeutic exercises to facilitate the active contraction of the quadriceps musculature.

Snyder-Mackler et al [50] examined the effect of electrical stimulation on the quadriceps musculature during 4 weeks of rehabilitation following ACL reconstruction. The authors noted that the addition of neuromuscular electrical stimulation to postoperative exercises resulted in stronger quadriceps and more normal gait patterns than those in patients exercising without electrical stimulation. Delitto et al [51] reported similar results of both the quadriceps using electrical stimulation for a 3-week training period following ACL reconstruction.

Snyder-Mackler et al [52] further studied the effects of electrical stimulation on quadriceps muscle strength following ACL reconstruction. Following a comparable 4-week training period, patients exercising with the adjunct of a high-intensity electrical

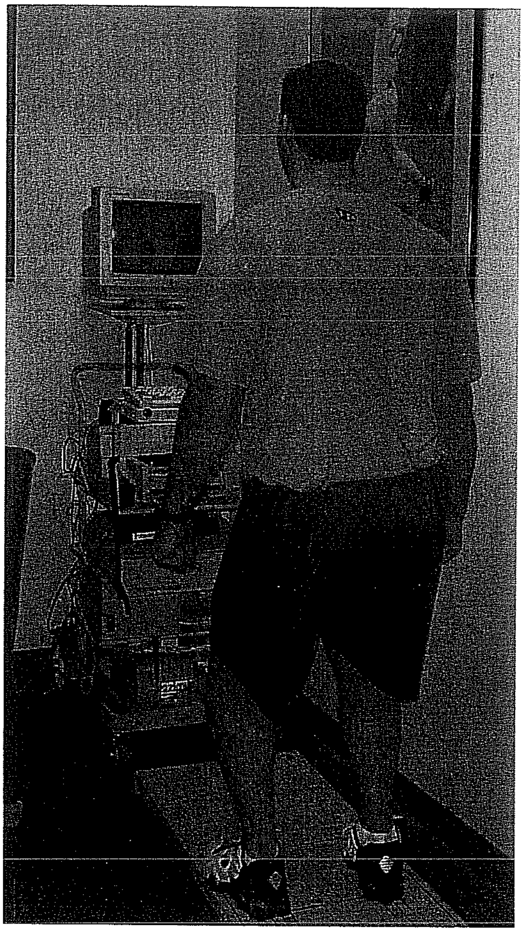

Fig. 3. A force platform (NeuroCom Balance System, NeuroCom International, Clackamas, OR) is used to assess the percentage of body weight the patient assumes on the involved leg while performing mini squats.

stimulation unit exhibited quadriceps strength greater than 70% of the uninvolved lower extremity. Patients not using electrical stimulation presented with quadriceps strength of only 57% of the opposite knee in the same time period following surgery.

Draper and Ballard [53] compared the use of electrical stimulation with biofeedback in the recovery of quadriceps strength following ACL reconstruction. Rehabilitation began immediately postsurgery and continued for the first 6 weeks postoperatively. Both groups produced a significant increase in quadriceps peak torque. The group of patients using biofeedback showed slightly greater peak torque output of the quadriceps than did the group using electrical stimulation.

The use of electrical stimulation and biofeedback on the quadriceps musculature appears to facilitate the return of muscle activation and may be valuable additions to therapeutic exercises. Clinically, we use electrical stimulation immediately following surgery while performing isometric and isotonic exercises such as quadriceps sets, straight leg raises, hip adduction and abduction, and knee extensions from 90° to 40° of knee flexion [54]. Electrical stimulation is used prior to biofeedback when the patient presents acutely with the inability to activate the quadriceps musculature. Once independent muscle activation is present, biofeedback may be utilized to facilitate further neuromuscular activation of the quadriceps. The patient must concentrate on neuromuscular control to activate the quadriceps independently during rehabilitation.

Restore neuromuscular control

As previously stated, the emphasis of rehabilitation programs has shifted over the past several years to focus on restoring proprioception, dynamic stability, and neuromuscular control in ACL-reconstructed knees. The neuromuscular control system may have a critical effect on the prevention of serious knee injuries [31]. Numerous authors have shown a decrease in proprioceptive and kinesthetic abilities following injury to the ACL [55–59]. Beard et al [60] examined the effects of applying a 100 N anterior shear force on ACL-deficient knees, and noted a deficit in reflexive activation of the hamstring musculature. Wojtys and Huston [61], furthermore, examined the neuromuscular deficits in 40 normal subjects and 100 ACL-deficient subjects. In response to an anteriorly directed tibial force, the ACL-deficient group showed deficits in muscle timing and recruitment order.

We routinely begin basic proprioceptive training during the second postoperative week, pending adequate normalization of pain, swelling, and quadriceps control. Proprioceptive training initially begins with basic exercises such as joint repositioning and closed kinetic-chain weight-shifting. Weight shifts may be performed in the medial-lateral direction and in diagonal patterns. Mini-squats are also performed early postoperatively. A force platform (eg, NeuroCom Balance System, NeuroCom International) may be incorporated with weight shifts and mini-squats to measure the amount of weight distribution between the involved and noninvolved extremity. Several authors have reported that an elastic bandage worn postoperatively has a positive impact on proprioception and joint position sense, and thus our patients are encouraged to wear an elastic support wrap underneath their brace as well [62,63].

As the patient advances, by approximately the end of week 2, mini-squats are progressed onto an unstable surface such as foam or a tilt board. The patient is instructed to squat down to approximately 25° to 30° and hold the position for 2–3 seconds while stabilizing the tilt board. Wilk et al [54] have shown the greatest amount of hamstring and quadriceps cocontraction occurred at approximatly 30° of knee flexion during the squat. Squats may be performed with the tilt board positioned in the medial-lateral and anterior-posterior directions. Markolf et al [64] have shown that muscular contraction can decrease the varus and valgus laxity in the knee joint threefold. Also, Baratta et al [65] have shown an increased risk of ligamentous injury in knees with quadriceps to hamstring muscle strength imbalances. Thus, we believe by improving neuromuscular coactivation stability is enhanced.

As proprioception is advanced, drills to encourage preparatory agonist-antagonist coactivation during functional activities are incorporated. These dynamic stabilization drills begin during the first 2–3 weeks with single leg stance on flat ground and unstable surfaces, cone-stepping, and lateral lunge drills. The patient may perform forward, backward, and lateral cone step-over drills to facilitate gait training, enhance dynamic stability, and to train the hip to help control forces at the knee joint. The patient is instructed to raise the knee up to the level of the hip and step over a series of cones, landing with a slightly flexed knee. These cone drills may also be performed at various speeds to train the lower extremity to stabilize with different amounts of momentum dynamically. The dip walk exercise may also be used to help train the hip to assist in controlling the knee. The patient executes a lateral step up on the balance beam and then steps forward, alternating the lateral step up on the opposite extremity. The patient continues this for the length of the beam in the forward and backward directions.

Lateral lunges are also performed with the patient instructed to lunge to the side, landing on a slightly flexed knee and holding that position for 1–2 seconds before returning to the start position. We use a functional progression for the lateral lunges: straight-plane lateral lunges are performed first, progressing to multiple-plane/diagonal lunges; lateral lunges with rotation; and, finally, lateral lunges onto foam (Fig. 4). As the patient progresses, concentration may be distracted by including a ball toss with any of these exercises to challenge the preparatory stabilization of the lower extremity with minimal conscious awareness.

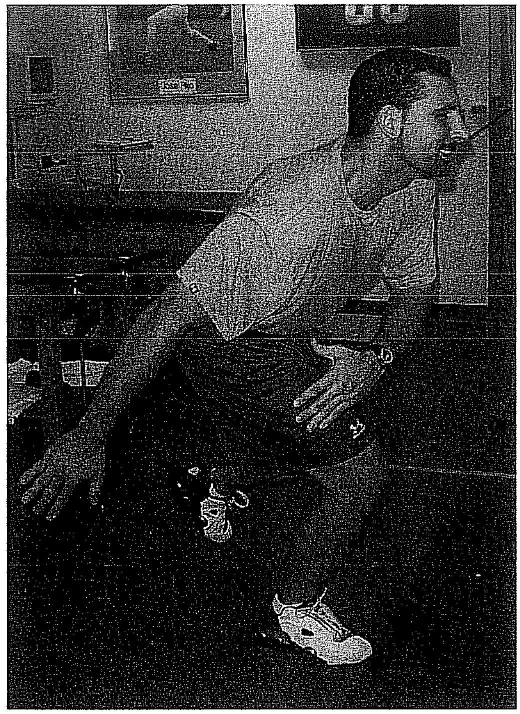

Fig. 4. Lateral lunges are performed using sportcord as resistance while landing onto a foam pad and catching a ball. The patient is instructed to land and maintain knee flexion of 30° during the drill.

Single leg balance exercises are progressed by altering the patient's center of gravity and incorporating movement of the upper extremity and the uninvolved lower extremity. The patient stands on a piece of foam with the knee slightly flexed and performs random flexion, extension, abduction, adduction, and diagonal movement patterns of the upper extremity while holding weighted balls and maintaining control of the knee joint. The uninvolved lower extremity may also be moved in the anterior-posterior or medial-lateral directions while maintaining control of the joint. Finally, both upper extremity and lower extremity movements may be combined. The patient again stabilizes the flexed knee on a piece of foam as the upper extremity moves forward with simultaneous extension of the lower extremity. This movement is followed by the upper extremity extending while the lower extremity moves forward (Fig. 5). These single leg balance drills are used with extremity movement to provide mild variations of the patient's center of gravity and thus altering the amount of dynamic stabilization needed as well as recruiting various muscle groups to provide the majority of neuromuscular control.

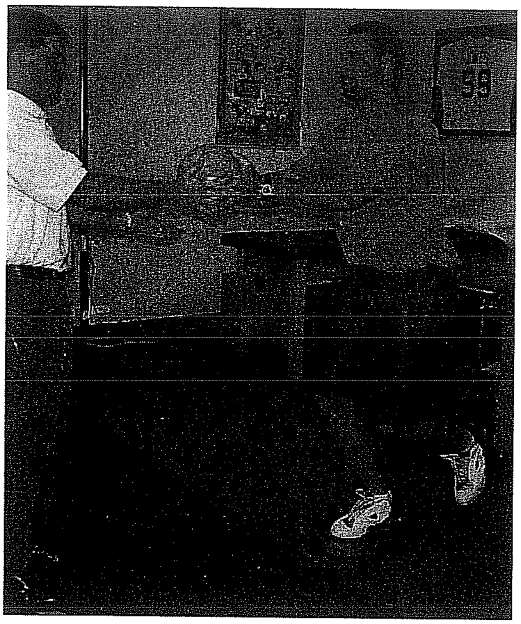

Fig. 5. Single-leg stance on foam while performing upper and lower extremity movements and holding onto a medicine ball. The clinician can perform a perturbation by striking the ball with the hand to cause a postural disturbance.

Medicine balls of progressive weight may be incorporated to provide further challenge to the neuromuscular control system.

Perturbation training may also be incorporated at approximately week 2–3. Wilk et al [29] emphasized the importance of perturbation training in ACL patients in 1999. Later Fitzgerald et al [66] examined the efficacy of perturbation training in the rehabilitation program of ACL-deficient knees. The authors reported that perturbation training resulted in more satisfactory outcomes and lessened the frequency of subsequent giving-way episodes in ACL-deficient knees. Therefore, we have emphasized perturbation training since 1995. We incorporate perturbations while the patient performs double or single leg balance on a tilt board. While flexing the knee to approximately 30°, the patient stabilizes the tilt board and begins throwing and catching a 3–5 lb. medicine ball. The patient is instructed to stabilize the tilt board in reaction to the sudden outside force produced by the weighted ball. The rehabilitation specialist may also provide manual perturbations by striking the tilt board (Fig. 6) with their foot to create a sudden disturbance in the static support of the lower extremity, requiring the patient to stabilize the tilt board with dynamic muscular contractions. Perturbations may also be performed during this drill by tapping the patient at their hips to provide proximal and distal perturbation forces.

Another drill designed to produce neuromuscular control with perturbation training includes dip walking and lateral side stepping on the balance beam with the patient attached to resistance tubing. The rehabilitation specialist may provide a perturbation by pulling and releasing the resistance cord, altering the amount of outside force applied during the movement pattern.

Closed kinetic chain exercises performed on the involved extremity are also utilized to train the neuromuscular control system. Specific neuromuscular control drills designed to control valgus and varus moments dynamically at the knee include front step-downs, lateral step-ups, and single-leg balance drills. Chmielewski et al [67] evaluated several weight-bearing activities in ACL-deficient and ACL-reconstructed knees and noted a strong correlation between functional outcome scores and the ability to perform the front step-down exercise.

Exercises such as balance beam walking, lunges onto an unstable surface, and step-up exercises while standing on an unstable surface are also used to strengthen the knee musculature while requiring the

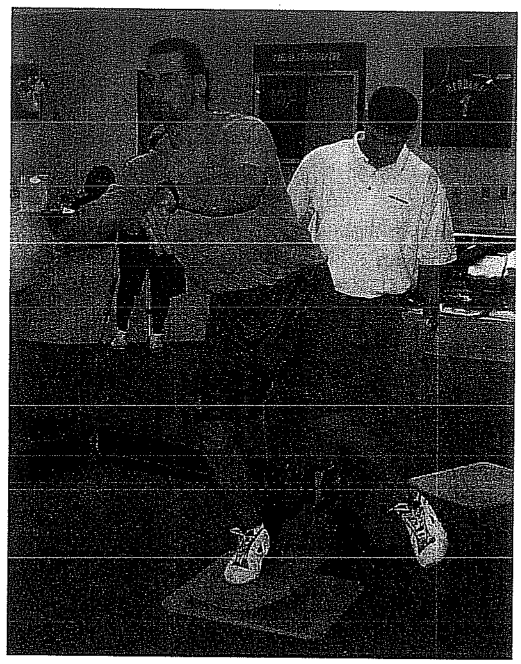

Fig. 6. Single-leg stance (knee flexed at 30°) performed on a tilt board while throwing and catching a plyoball. Manual perturbations are performed by tapping the tilt board with the clinician's foot.

muscles located proximally and distally within the kinetic chain to stabilize and allow coordinated functional movement patterns.

Plyometric jumping drills may also be performed to facilitate dynamic stabilization and neuromuscular control of the knee joint. Plyometric exercises use the muscle's stretch-shortening properties to produce maximal concentric contraction following a rapid eccentric loading of the muscle tissues [68,69]. Plyometric training is used to train the lower extremity to produce and dissipate forces to avoid injury.

Hewett et al [70] examined the effects of a 6-week plyometric training program on the landing mechanics and strength of female athletes. The authors reported a 22% decrease in peak ground reaction forces and a 50% decrease in the abduction/adduction moments at the knee during landing. Also, a significant increase in hamstring isokinetic strength, hamstring to quadriceps ratio, and vertical jump height were reported.

Using the same plyometric program, Hewett et al [71] prospectively analyzed the effect of neuromuscular training on serious knee injuries in female athletes. The authors reported a statistically significant decrease in the amount of knee injuries in the trained group versus the control group.

Plyometric activities are typically initiated during week 8 for our competitive athletes with plyometric jumping on the leg press machine. Plyometrics are only performed by the competitive, not the recreational athlete. The leg press machine is initially used to control the amount of weight and ground reaction forces as the athlete learns how to perform jumping drills correctly. The patient is instructed to land softly on the toes with the knees slightly flexed to maximize force dissipation of the surrounding stabilizing musculature and to avoid knee hyperextension. Plyometric drills are then progressed to the flat ground to include ankle hops; jumping in place; lateral, diagonal, and rotational jumping; bounding; and skip lunging. Flat ground plyometrics are progressed to incorporate single and multiple boxes (Fig. 7). We usually begin plyometric activities with two-leg jumps, progressing to single-leg jumps.

The final aspect of rehabilitation regarding neuromuscular control involves enhancing muscular endurance. Proprioceptive and neuromuscular control has been shown to diminish once muscular fatigue occurs [72–74]. Exercises such as bicycle, stair climbing, elliptical machines, and slide boards may be used for long durations to increase endurance as well as high repetition, low-weight resistance strengthening. Additionally, we frequently recommend performing neuromuscular control drills toward the end of a treatment session, after cardiovascular training. This type of training is performed to challenge the neuromuscular control of the knee joint when the dynamic stabilizers have been adequately fatigued.

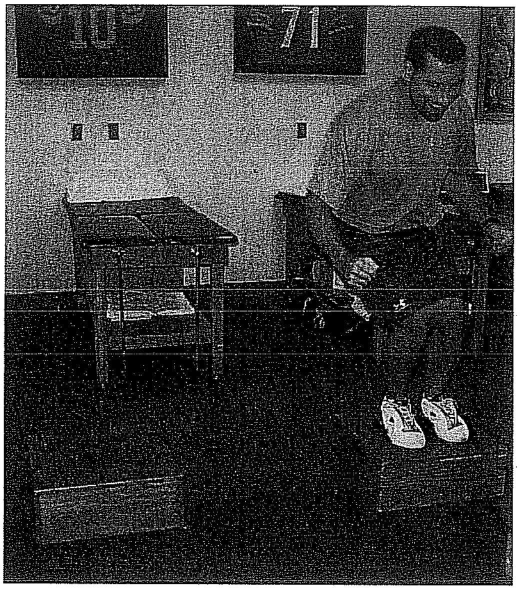

Fig. 7. Two-legged lateral plyometric jumping drills. The patient is instructed to land on the boxes and flat ground with the knee in a flexed position.

Gradually increase applied loads

The next principle of ACL rehabilitation involves gradually increasing the amount of stress applied to the injured knee. The rehabilitation process involves a progressive application of therapeutic exercises designed to increase function gradually in the post-operative knee. The progression of weight-bearing and range-of-motion restoration, as previously discussed, involves a gradual progression to assure that complications such as excessive motion restrictions or scar tissue formation are avoided while progressing steadily to avoid overstressing the healing tissue. An over-aggressive approach early within the rehabilitation program may result in increased pain, inflammation, and effusion. This simple concept may also be applied to the progression of strengthening exercises, proprioception training, neuromuscular control drills, functional drills, and sport-specific training. For example, exercises such as weight shifts and lunges are progressed from straight plane anterior-posterior or medial-lateral directions to involve multi-plane and rotational movements. Two-legged exercises, such as leg press, knee extension, balance activities, and plyometric jumps, are progressed to single-leg exercises. The goal, furthermore, is to increase the applied loads gradually on the ACL graft, which results in tissue hypertrophy and tissue alignment.

The athlete's return to sport specific-specific drills progresses through a series of transitional drills designed to challenge the neuromuscular control system progressively. Pool running is performed prior to flat-ground running; backward and lateral running are performed prior to forward running; plyometrics are performed prior to running and cutting drills, and finally sport-specific agility drills.

Thus, the progression through the postoperative rehabilitation program involves a gradual progression of applied and functional stresses. This progression is used to provide a healthy stimulus for healing tissues while assuring that forces are gradually applied without causing damage. This assures that the patient has ample time to develop the neuromuscular control and dynamic stabilization needed to perform these drills.

Emphasize functional drills

The integration of functional activities is necessary to train the injured patient to perform specific movement patterns necessary for everyday activities. Forward and backward cone step-over drills are used to facilitate a normal gait pattern. The use of the pool may also assist in the restoration of function in the patient as well. The decreased amount of body weight from the buoyancy of the water provides an ideal environment for exercises to normalize weight distribution and gait training. Lateral step-ups and front step-downs are also used to simulate the concentric and eccentric quadriceps activity observed during the ascent and descent phases of stair ambulation.

Also related to functional drills is the concept of total body strengthening. Neuromuscular control at the knee is provided by the precise interaction of the stabilizing structures of the entire lower-extremity kinetic chain, including the ankle, knee, hip, and core musculature. Therefore, exercises to enhance strength, flexibility, endurance, and neuromuscular control must be addressed for the entire lower extremity and core musculature.

Progress to sport-specific training

The last principle of ACL rehabilitation involves the restoration of function through sport-specific training for athletes returning to competition. The intention of sport-specific training is to simulate the functional activities associated with sports while incorporating peripheral afferent stimulation with reflexive and preprogrammed muscle control and coactivation. Many of the previously discussed drills, such as cone drills, lunges with sport cord, plyometrics drills, and running and agility progression may be modified based on the specific functional movement patterns associated with the patient's unique sport. Some of the sport-specific running and agility drills incorporated include side-shuffle, cariocas, sudden starts and stops, 45° cutting, 90° cutting, and various combinations of the previous drills. The specific movement patterns learned throughout the rehabilitation program are integrated to provide challenge in a controlled setting. These drills are performed to train the neuromuscular control system to perform during competition in a reflexive pattern to prevent injuries.

Variations in rehabilitation based on graft type

The graft selection has some effect on the rehabilitation following ACL reconstruction. Today, the most commonly utilized sources of graft tissue are the autogenous patellar bone-tendon-bone (BTB) [37,75] and autogenous hamstring tendons [76–78]. Some physicians utilize an allograft tissue [79–81] and quadriceps tendon [82,83,127]. Based on differences in graft tissue strength, stiffness, and graft fixation strength, the postoperative rehabilitation should vary.

The ultimate load to failure of various tissues has been reported by several investigators. Table 1 illustrates these differences. Note that the quadrupled hamstring tendon graft is approximately 91% stronger than the native ACL and 39% stronger than the patellar tendon. The patellar tendon graft is approximately 37% stronger than the native ACL. Age significantly affects graft strength [128] although all potential grafts listed in Table 1 are stronger than the native ACL, graft fixation strength must be factored into the equation when developing a rehabilitation program.

Empirically, it would appear that healing of bone to bone in the osseous tunnel would be faster than tendon to bone. This has not been scientifically proven, however. With delayed healing of tendon to bone, furthermore, aggressive rehabilitation/activities may appear to cause graft stretch-out. Also, the theoretical advantage of a larger, stronger allograft allowing for more aggressive rehabilitation remains unproven as well [84].

Table 1
Ultimate load to failure and stiffness of various graft selections

Graft selection	Ultimate strength to failure (N)	Stiffness (N/M)
Native ACL [128]	2160	240
Patellar tendon [129]	2977	455
Quadrupled hamstring [125]	4140	807
Quadriceps tendon [127]	2353	326

Abbreviations: ACL, anterior cruciate ligament; N, Newtons; N/M, Newton-meters.

Recently, Brand et al [85] reported biomechanical data on various graft fixation techniques for ACL reconstruction. The authors noted tibial fixation strength for a patellar BTB graft was highest with a 9 mm interference screw (load to failure 678–758 N) [86]. The femoral fixation of the BTB graft was optimal with a metal interference screw (640 N) [87,88]. Conversely, fixation strengths were also reported for soft tissue grafts. Hamstring graft tibial fixation was greatest with a washerplate (9.5 N) [89], and with an endobutton with #5 suture on the femoral side (Brown et al, unpublished data, 1996). Noyes et al have estimated the strength required for activities of daily living to be 454 N based on the failure strength of the ACL [90].

Our clinical approach to developing and designing a rehabilitation program based on ACL graft selection is to be less aggressive initially with soft tissue grafts such as the quadrupled hamstring grafts. This is based on the premise that soft tissue to bone healing takes approximately 12 weeks, whereas bone to bone healing occurs in approximately 8 weeks in most instances. We will briefly discuss the specific differences between the various graft types.

As previously discussed, we have developed two slightly different rehabilitation programs for patients who have undergone ACL reconstruction using a patellar tendon BTB graft. The accelerated approach is utilized for individuals who are younger and want to return to competitive athletics. This program is outlined in Box 1. The program emphasizes early proprioception training (week 1), perturbation training (week 2–3), limited weight-bearing plyometrics (weeks 8–10), early running (weeks 8–10), and an early return to sports (weeks 16–20). By contrast, patients who are active but perhaps returning to recreational sports, and a slightly older patient, would be placed into the regular approach (Box 2) following patellar tendon BTB ACL reconstruction. This program is slightly slower than the accelerated program. During this program, the emphasis is on early proprioception (week 2), perturbation training (weeks 4–6), no plyometric training, running at weeks 14–16, and return to sports at 6–9 months.

At our center, the use of hamstring tendons to reconstruct the ACL is reserved for the less active and older patient who is not returning to demanding sports that involve running and cutting, and in those with pre-existing patellofemoral problems. Several physicians may prefer hamstring grafts for their female athletes to minimize postoperative patellofemoral complications. The rehabilitation program following hamstring tendon ACL reconstruction is slightly different from the patellar tendon BTB program. First, it appears clinically that early aggressive hamstring-resistive exercises following hamstring graft harvest may result in irritation of the remaining semimembranosus from the semitendinosus as it scars down. This will present to the patient as a sensation of a hamstring strain, and the patient will experience discomfort. Avoidance of early aggressive hamstring resistive exercises during the first 6 weeks appears to eliminate this complication. We do not allow hamstring strengthening for 4 weeks, submaximal isometric contractions are allowed from week 5–6, then light resisted hamstrings from 6–8 weeks. At 8 weeks, the patient is allowed to progress to a progressive resistance strengthening program. Despite delaying hamstring strengthening exercises, hamstring strength returns to normal by 6–12 months from surgery [78,91]. Other rehabilitation differences between patellar tendon and hamstring grafts include no running for 12 weeks, no jumping for 12–14 weeks, no twisting or hard cutting for 16 weeks, and a return to sports at $5^{1/2}$–6 months. Several authors have reported 85% to 93% good to excellent results using hamstring grafts for ACL reconstruction in athletes [76,77]. Aglietti et al [92] compared the results of hamstring tendons grafts with patellar tendon (BTB) grafts in a 60 consecutive patient series. The results indicated no significant overwhelming differences between the two types of grafts. With the patellar tendon graft group, however, there was a trend toward better objective stability, but there was more extension loss , as well as patellofemoral complaints. Conversely, the semitendinosus group tended to be slightly looser on KT testing but had less patellofemoral complications. These results are similar to the findings of Marder et al [93].

Our rehabilitation program for the allogenous patellar tendon BTB graft is similar to the autogenous graft. Whether the patient is placed on the accelerated or regular program is based on patient type, desired

Box 2. Rehabilitation following ACL-PTG reconstruction (regular program)

Immediate postoperative phase

POD 1

Brace—EZ Wrap brace locked at 0° extension, or Protonics Rehab System (PRS) as directed by physician
Weight-bearing—2 crutches as tolerated
Exercises:
- Ankle pumps
- Passive knee extension to 0
- Straight leg raises
- Quad sets, glut sets
- Hamstring stretch

Muscle stimulation—muscle stimulation to quads (4 hours per day) during quad sets
CPM—PRN, 0° to 90° as tolerated (as directed by physician)
Ice and evaluation—ice 20 minutes out of every hour, and elevate with knee in extension

POD 2 to 3

Brace—EZ Wrap brace locked at 0° extension for ambulation and unlocked for sitting, etc., or Protonics Rehab System (PRS) as directed by physician
Weight-bearing—2 crutches, weight-bearing as tolerated
Range-of-motion—patient out of brace 4 to 5 times daily to perform self ROM
Exercises:
- Multi-angle isometrics at 90°and 60° (for quads)
- Knee extension 90° to 40°
- Intermittent ROM exercises continued
- Patellar mobilization
- Ankle pumps
- Straight leg raises (multi-plane)
- Standing weight shifts and mini squats (0° to 30° ROM)
- Hamstring curls
- Continue quad sets/glut sets

Muscle stimulation—electrical muscle stimulation to quads (6 hours per day)
CPM—0° to 90°
Ice and elevation—ice 20 minutes out of every hour, and elevate with knee in extension

POD 4 to 7

Brace—EZ Wrap brace locked at 0° extension for ambulation and unlocked for sitting, etc., or Protonics Rehab System (PRS) as directed by physician
Weight-bearing—2 crutches, weight-bearing as tolerated
Range-of-motion—patient out of brace or in PRS to perform ROM 4 to 5 times daily
Exercises:
- Knee extension 90° to 40° degrees
- Intermittent PROM exercises
- Patellar mobilization
- Ankle pumps
- Straight leg raises (multi-plane)
- Standing weight shift and mini squats (0° to 30°)
- Passive knee extension to 0°
- Hamstrings curls
- Proprioceptive and balance activities

Muscle stimulation—electrical muscle stimulation (continue 6 hours daily)
CPM—0° to 90°

Maximum protection phase (week 2–3)

Criteria to enter phase 2
- Quad control (ability to perform good quad set and SLR)
- Full passive knee extension
- PROM 0° to 90°
- Good patellar mobility
- Minimal effusion
- Independent ambulation with one or two crutches

Goals:
- Absolute control of external forces and protect graft
- Nourish articular cartilage
- Decrease fibrosis
- Stimulate collagen healing
- Decrease swelling
- Prevent quad atrophy

Week 2

Goals:

Prepare patient for ambulation without crutches

Brace—EZ Wrap locked at 0° for ambulation only, unlocked for self ROM (4–5 times daily), or PRS program as indicated

Weight-bearing—as tolerated (goal to discontinue crutches 7–10 days postop)

Range-of-motion–self ROM (4–5 times daily), emphasis on maintaining 0° passive extension

KT 2000 Test—(15 lb anterior-posterior test only)

Exercises:

- Muscle stimulation to quadriceps during quadriceps exercises
- Multi-angle isometrics at 90, 60, 30°
- Leg raises (4 planes)
- Hamstring curls
- Knee extension 90° to 40°
- Mini squats (0° to 40°) and weight shifts
- PROM 0° to 105°
- Patellar mobilization
- Hamstring and calf stretching
- Proprioception training
- Well leg exercises
- Progressive resistive program (PRE) Program–start with 1 lb., progress 1 lb. per week

Swelling control—ice, compression, elevation

Week 3

Brace—discontinue locked brace. Brace opened 0° to 125° for ambulation.

Range-of-motion—self ROM (4–5 times daily), emphasis on maintaining 0° passive extension

Full weight-bearing—no crutches

Exercises:

- Same as week 2
- PROM 0° to 115°
- Bicycle for ROM stimulus and endurance
- Pool walking program
- Initiate eccentric quads 40° to 100° (isotonic only)
- Leg press (0° to 60°)
- Stair stepping machine

Controlled ambulation phase (weeks 4–7)

Criteria to enter phase 3

- AROM 0° to 115°
- Quad strength 60% > contralateral side (isometric test) (60° knee flexion angle)
- Unchanged KT Test (+1 or less)
- Minimal effusion

Goals:

Control Forces during walking

Brace—discontinue brace

Range-of-motion—self ROM (4–5 times daily), emphasis on maintaining 0° passive extension

KT 2000 Test—(week 4, 20 lb. anterior and posterior test)

(Weeks 6, 20, and 30 lb. anterior and posterior test)

Exercises:

- Same as week 3
- PROM 0° to 130°
- Initiate swimming program
- Initiate step-ups (start with 2′ and gradually increase)
- Increase closed kinetic chain rehab
- Increase proprioception training

Moderate protection phase (weeks 7–12)

Criteria to enter phase 4

- AROM 0° to 125°
- Quad strength 60% of contralateral leg (isokinetic test)
- No change in KT scores (+ 2 or less)
- Minimal effusion
- No patellofemoral complaints
- Satisfactory clinical exam

Goals:

Protect patellofemoral joint's articular cartilage

Maximal strengthening for quads, lower extremity

KT 2000 Test—(week 10); total displacement at 15, 20, and 30 lbs.; Manual Maximal Test

Isokinetic Test—(week 10)

Exercises:
- Emphasize eccentric quad work
- Continue closed chain exercises, step-ups, mini-squats, leg press
- Continue knee extension 90° to 40°
- Hip abduction/adduction
- Hamstring curls and stretches
- Calf raises
- Bicycle for endurance
- Pool running (forward/backward)
- Walking program
- Stair Master
- Initiate isokinetic work 100° to 40°

Light activity phase (Month 2 1/2–3 1/2)

Criteria to enter phase 5
- AROM 0° to 125°
- Quad strength 70% of contralateral side, knee flexor/extensor rated 70% to 79%
- No change in KT scores (+ 2 or less)
- Minimal/no effusion
- Satisfactory clinical exam

Goals:
Development of strength, power, and endurance
Begin to prepare for return to functional activities
Tests—isokinetic test (weeks 10–12 and 16–18)

Exercises:
- Continue strengthening exercises
- Initiate plyometric program
- Initiate running program
- Initiate agility drills
- Sport-specific training and drills

Criteria to initiate running program
- Satisfactory isokinetic test
- Unchanged KT results
- Functional test 70% > contralateral leg
- Satisfactory clinical exam

Return to activity phase (month 3 1/2–4 1/2)

Criteria to return to activities
- Isokinetic test that fulfills criteria
- KT 2000 Test unchanged
- Functional test 85% > contralateral leg
- Proprioceptive test 100% of contralateral leg
- Satisfactory clinical exam

Goals:
Achieve maximal strength and further enhance neuromuscular coordination and endurance
Tests–isokinetic test prior to return, KT 2000 test, functional test

Exercises:
- Continue strengthening program
- Continue closed chain strengthening program
- Continue plyometric program
- Continue running and agility program
- Accelerate sport-specific training and drills

6-Month follow-up
Isokinetic test
KT 2000 test
Functional test

12-month follow-up
Isokinetic test
KT 2000 test
Functional test

activities level, and concomitant injuries/surgeries. Several authors have described the rehabilitation program following allogenous PT BTB grafts [14,23,80]. Most authors agree that allograft tissue reduces the incidence of anterior knee pain [14] but quadriceps weakness still occurs.

Variations based on concomitant procedures

Rehabilitation following ACL reconstruction must be modified if concomitant injuries are present. The rehabilitation progression, in particular the progression of range-of-motion and weight-bearing status, is often modified based on the specific healing constraints of each concomitant pathology. Injuries that are often associated with acute ACL ruptures include medial and lateral collateral ligament injuries, posterior cruciate ligament (PCL) injuries, meniscal damage, and articular cartilage defects.

Medial collateral ligament injury

Hirshman et al [94] reported a 13% incidence of combined ACL/medial collateral ligament (MCL) injuries in acute knee ligament injuries. Isolated MCL injuries are often treated nonoperatively; however, when combined with ACL disruption, grade III MCL injuries may require surgical intervention because of the loss of the ACL as a secondary restraint to valgus stress. Although grade I and II MCL sprains may not require surgical intervention, they may require special attention in the rehabilitation process because of the increased pain and excessive scarring of the medial capsular tissues. The treatment approach to combined ACL and MCL injury is similar to the isolated ACL injury, with progression through the protocol often altered because of the increased effusion and subsequent increase in loss of motion present with the combined tissue damage. Given the extent of tissue damage and the presence of extra-articular vascularity, combined ACL and MCL injuries often present with excessive scar tissue formation and thus should follow a slightly more accelerated progression for range-of-motion. Range-of-motion complications from excessive extra-articular scarring should be minimized, with particular emphasis on achieving full passive knee extension. Furthermore, exercises that place excessive strain on the healing MCL, such as hip adduction, should be carefully monitored.

Medial collateral ligament tears from the proximal origin or within the midsubstance of the ligament tend to present with increased stiffness without residual laxity. By contrast, MCL injuries at the distal insertion site tend to have less of a healing response and often exhibit residual valgus laxity [95]. Therefore, the location of ligament damage may also affect the rehabilitation program. Injuries involving the distal aspect of the MCL may be progressed more cautiously to allow for tissue healing whereas injury to the midsubstance or proximal ligament may require a slightly accelerated restoration of range-of-motion to prevent excessive scar tissue formation.

Lateral collateral ligament injury

The incidence of concomitant lateral collateral ligament (LCL) injuries is far less common than those of the MCL. Hirshman et al [94] report a 1% incidence of combined ACL/LCL injuries in acute knee injuries. ACL with concomitant LCL pathology or posterolateral capsular damage usually do not exhibit the same scarring characteristics as the ACL/MCL injuries. Thus, progression for LCL injuries is usually slower than that for the MCL to allow adequate healing. Restoration of range-of-motion is not altered, although weight-bearing may progress slightly slower, progressing to full weight-bearing by approximately 14 days. As with the MCL, exercises that produce excessive varus stress are progressed with caution and should be monitored carefully for symptoms. If the patient, futhermore, exhibits a varus thrust during ambulation, then a functional brace may be useful to control the varus moment.

Posterior cruciate ligament injury

Injuries involving the ACL and PCL are relatively rare but may have severe complications if associated with neurologic or vascular compromise. Although controversy exists regarding the optimal care of these injuries, several authors have reported better functional outcomes when the ACL and PCL are surgically reconstructed rather than treated conservatively [96,97]. It has been our clinical experience, furthermore, that ACL/PCL injuries treated acutely have better long-term functional outcomes [98].

Postoperative rehabilitation for acute reconstructions involves early motion and weight-bearing with a gradual restoration of knee flexion (Box 3)[99,100]. Range-of-motion is progressed from 0° to 65° on day 5, to 0° to 75° on day 7, 0° to 90° on day 10°, 0° to 100° in week 2, 0° to 115° in week 6, and 0° to 125° and beyond beginning in week 7%. Weight-bearing is progressed from 50% body weight on day 7% to 75% body weight on day 12, and finally full weight-bearing by week 4. A brace is used for the first 7–8 weeks. Patients are often fitted for functional knee braces on discharge of the postoperative knee brace. Closed kinetic chain exercises are initiated during week 3 with weight shifts and mini-squats and progress to include leg press, aquatic therapy, and bicycle by week 4. Return to functional activities is allowed beginning with a walking program in week 12, progressing to light running in week 16, and more aggressive agility drills by 5 months.

Meniscus pathology

Meniscal injuries occur in approximately 64% to 77% of acute ACL injuries [84]. Shelbourne et al [101] stated that meniscal tears in the ACL-injured knee typically occur traumatically and are nondegenerative in nature in comparison with meniscal tears in ACL-intact knees.

If meniscal pathology is present, a partial meniscectomy or meniscus repair may be necessary to

Box 3. Rehabilitation following combined arthroscopic anterior and posterior cruciate ligament reconstruction

Immediate postoperative phase (days 1 – 13)

Goals:
- Restore full passive knee extension
- Diminish joint swelling and pain
- Restore patellar mobility
- Gradually improve knee flexion
- Re-establish quadriceps control
- Restore independent ambulation

PODs 1 to 4

Brace:
- Drop lock brace locked at 0° extension with compression wrap
- Sleep in brace

Weight-bearing:
- Two crutches as tolerated (less than 50%)

Range-of-motion:
- Range-of-motion 0° to 45/50°
- CPM 0° to 60° as tolerated

Exercises:
- Ankle pumps
- Quad sets
- Straight leg raising—flexion, abduction, adduction in brace
- Muscle stimulation to quadriceps (4 hours per day) during quad sets and straight leg raises

Patellar mobilizations 5 to -6 × daily

Ice and elevation every 20 minutes of each hour with knee in extension

PODs 5 – 13

Brace:
- Continue use of drop lock brace locked at 0° extension during ambulation and sleep

Weight-bearing:
- Two crutches: gradually increase weight-bearing to 50% by day 7; 75% by day 12

Range-of-motion:
- Day 5: 0° to 65°
- Day 7: 0° to 75°
- Day 10: 0° to 85/90°
- Day 13: 0° to 90°
- Gradually increase CPM ROM 0° to 70° day 7; 0° to 90° day 12

Exercises:
- Continue previous exercises
- Initiate knee extension 60° to 0°
- Continue use of muscle stimulation
- Patellar mobilizations 5 to 6× daily

Continue use of ice, elevation, and compression

Maximum protection phase (weeks 2 – 6)

Criteria to Enter phase 2:
- Good quad control (ability to perform good quad set and SLR)
- Full passive knee extension
- PROM 0° to 90°
- Good patellar mobility
- Minimal joint effusion

Goals:
- Control deleterious forces to protect grafts
- Nourish articular cartilage
- Decrease swelling
- Decreased fibrosis
- Prevent quad atrophy
- Initiate proprioceptive exercises

Week 2

Brace:
- Continue use of brace locked at 0° of extension

Weight-bearing:
- As tolerated; approximately 75% body weight

Range-of-motion:
- Continue to perform passive ROM 5 to 6 × daily
- Day 14: 0° to 90°

Exercises:
- Continue quad sets and straight leg raises
- Continue knee extension 60° to 0°
- Multi-angle isometrics at 80°, 60° and 40°

- Patellar mobilizations 5 to 6 × daily
- Well leg bicycle
- Weight shifts
- Mini-squats (0° to 45°)
- Continue use of muscle stimulation

Continue ice, elevation, and compression

Week 3

Continue above-mentioned exercises

ROM: 0° to 90°

Continue use of 2 crutches—75% to 80% body weight

Week 4

Brace:
- Continue use of brace locked at 0° extension
- Discontinue sleeping in brace

Weight-bearing:
- Progress to weight-bearing as tolerated with 1 crutch

Range-of-motion:
- AAROM, PROM: 0° to 90/100°

Exercises:
- Weight shifts
- Mini-squats (0° to 45°)
- Knee extension 90° to 40° (therapist discretion)
- Light pool exercises and walking
- Initiate bicycle for ROM and endurance
- Begin leg press 60 - 0° (light weight)
- Proprioception/balance drills

KT-2000 testing performed—20 lb. (at 25° and 70°)

Week 5 to 6

Discontinue use of crutches week 5 to 6

Unlock brace for ambulation week 6

Fit for functional ACL/PCL brace

Range-of-motion week 5: 0° to 105°; week 6: 0° to 115°

Continue pool exercises

Initiate lateral lunges

Hip abduction and adduction

KT-2000 testing performed—30 lbs. at week 6

Moderate protection phase (weeks 7 – 12)

Criteria to Enter Phase 3:
- PROM 0° to 115°
- Full weight-bearing
- Quadriceps strength > 60% contralateral side (isometric test at 60°)
- Unchanged KT test (+ 1 or less)
- Minimal to no full-joint effusion
- No joint line or patellofemoral pain

Goals:

Control forces during ambulation

Progress knee range-of-motion

Improve lower extremity strength

Enhance proprioception, balance, and neuromuscular control

Improve muscular endurance

Restore limb confidence and function

Brace:
- Continue use of unlocked brace for ambulation—discharge week 7 to 8

Range-of-motion:
- AAROM/PROM 0° to 125°

Exercises:
- Continue previous exercises
- Initiate swimming
- Initiate lateral and front step-ups (2″ step, gradually increase)
- Progress closed kinetic chain exercises (squats 0° to 60°, leg press 90° to 0°)
- May begin light hamstring isotonics week 8
- Progress proprioceptive training

KT-2000 test: 20 and 30 lbs. at weeks 6 and 8

Controlled activity phase (weeks 13–16)

Criteria to Enter Phase 4:
- AROM 0° to 125°
- Quadriceps strength > 60 to 70 contralateral side (isokinetic test)
- No change in KT scores (+2 or less)
- Minimal effusion

- No patellofemoral complaints
- Satisfactory clinical exam

Goals:

Protect healing grafts
Protect patellofemoral joint articular cartilage
Normalize lower extremity strength
Enhance muscular power and endurance
Improve neuromuscular control

Exercises:

- Continue previous exercises
- Emphasis on eccentric quadriceps strengthening
- Continue closed kinetic chain mini-squats, step-ups, step-downs, lateral lunges, leg press
- Continue knee extension 90° to 40°
- Hip abduction and adduction
- Initiate front lunges
- Calf raises (gastrocnemius and soleus strengthening)
- Bicycle and Stair Master for endurance
- Initiate pool running (side shuffle, backward, forward)
- Initiate walking program
- Initiate isokinetic exercise 100° to 40° (120° to 240°/s spectrum)

KT-2000 test at week 12
Isokinetic testing at week 12 (180° and 300°/s)

Light activity phase (months 4–6)

Criteria to enter Phase 5:

- AROM > 125°
- Quadriceps strength 70% of contralateral side; flexion/extension ratio 70% to 79%
- No change in KT scores (+2 or less)
- Minimal joint effusion
- Satisfactory clinical exam

Goals:

Enhancement of strength, power, and endurance
Initiate functional and/or sport-specific activity
Prepare for return to functional activities

Exercises:

- Continue strengthening exercises – emphasize quadriceps & co-contraction
- Initiate plyometric program month 4 to 5
- Initiate running program months 4 to 6
- Initiate agility drills month 5 to 6
- Initiate sport-specific training and drills month 5 to 6

Isokinetic strength test at week 16 and week 18

Criteria to initiate running program:

Acute reconstruction may begin at 4 to 5 months
Chronic reconstruction may begin at 5 to 6 months

- Satisfactory clinical exam
- Unchanged KT test
- Satisfactory isokinetic test

Quadriceps bilateral comparison (80% or greater)
Hamstring bilateral comparison (110% or greater)
Quadriceps torque/body weight ratio (55% or greater)
Hamstrings/quadriceps ratio (70% or greater)

- Proprioception testing 100% of contralateral side
- Functional hop test > 75% of contralateral leg

Return to activity phase (months 6–9)

Criteria to return to activities:

- Satisfactory clinical exam
- Unchanged KT test
- Satisfactory isokinetic test
- Proprioception testing 100% of contralateral side
- Functional hop test > 80% of contralateral leg

Goals:

Gradual return to full-unrestricted sports
Achieve maximal strength and endurance

Normalize neuromuscular control
Progress skill training

Exercises:

- Continue strengthening programs
- Continue proprioception & neuromuscular control drills
- Continue plyometric program
- Continue running and agility program
- Progress sport-specific training and drills

Clinical follow-ups at 6, 12, & 24 months postop:

KT-2000 testing
Isokinetic testing
Functional testing
Clinical exam

alleviate symptoms. An arthroscopic partial meniscectomy does not significantly alter the rehabilitation protocol. It may require additional time, however, before initiating a running or jumping program, depending on the amount of meniscal injury. If surgical repair of the meniscus is required, alteration to the rehabilitation program is warranted, although controversy exists regarding length of immobilization, weight-bearing status, and the return to pivoting sports [102]. Cannon et al [103] reported meniscal healing is increased significantly if the ACL is reconstructed.

It is our belief that long-term complications may arise from lengthy immobilization or avoidance of weight-bearing. For patients undergoing concomitant ACL reconstruction with meniscus repair, range-of-motion and weight-bearing progression is slightly slower, depending on the extent of meniscal damage. Complex tears are progressed much slower than peripheral tears of the menisci. Also, isotonic hamstring strengthening is limited for 8–10 weeks in order to allow adequate healing of the repaired meniscus because of the close anatomic relationship of the joint capsule to both the meniscus and hamstrings. The patient is not allowed to squat past 60° for 8 weeks and must avoid squats with twisting motions for at least 16 weeks.

Specific range-of-motion guidelines differ based on the extent and location of meniscal damage, although immediate motion with emphasis on full passive knee extension is constant. A tear isolated to the periphery of the meniscus should exhibit approximately 90° to 100° of flexion at week 2, 105° to 115° at week 3, and 120° to 135° by week 4. Complex meniscal tears follow a slightly slower approach with 90° to 100° of knee flexion by week 2, 105° to 110° by week 3, and 115° to 120° by week 4. Patients with complex meniscal repairs may also prolong the use of crutches and partial weight-bearing for an additional 1–2 weeks.

Barber and Click [102] evaluated the efficacy of an accelerated ACL rehabilitation program for patients with concomitant meniscus repair. At follow-up (24–72 months postoperative), 92% of repairs exhibited successful meniscal healing. whereas only 67% of meniscus repairs performed in ACL-deficient knees, and 67% of meniscus repairs performed in stable knees, exhibited successful healing. The authors suggest that the hemarthrosis and inflammatory process associated with ACL reconstruction may enhance meniscus healing and improve long-term results of meniscus repair with concomitant ACL reconstruction.

Articular cartilage pathology

The presence of articular cartilage defects may decelerate the weight-bearing status and time to return to strenuous activities, especially if present on weight-bearing surfaces of the femur or tibia. Johnson et al [104] reported that greater than 80% of acute ACL injuries present with osteochondral injuries, usually bone bruises. Several authors have shown similar rates of osseous lesions associated with ACL pathology, ranging from 71% to 85% [105–109]. Although the progression of rehabilitation is similar to an isolated ACL reconstruction, exercises that result in high shear or repetitive compressive loads must be delayed. Running, jumping, and a return to athletic activity are delayed to protect damaged articular surfaces. A prolonged return to full activity will ensure that the joint surfaces are gradually exposed to the high levels of sport-specific forces observed during many athletic activities without overloading the healing tissues. Johnson reported [110] that patients with bone bruises exhibited more swelling, more pain, longer periods of time with antalagic gait, and a longer period of time before feeling normal. Thus, the clinician may prefer to keep the patient on crutches longer if a significant bone bruise exists. The goal is to return the knee to homeostasis before strenuous sports or aggressive exercises are performed.

Patients who undergo an ACL reconstruction with articular cartilage lesions often undergo a microfracture or autologous chondrocyte implantation (ACI) in an attempt to stimulate healing and repair. These patients require a special type of rehabilitation program that stimulates articular cartilage healing without creating excessive shear forces to cause an articular cartilage defect. Although immediate motion and full passive knee extension are emphasized, weight-bearing is usually progressed slower, and running and jumping is delayed longer, than that of an isolated ACL reconstruction. The exact location and extent of the lesion determines the rate of weight-bearing progression.

For patients with ACL reconstruction with concomitant microfracture, the rate of progression of range-of-motion does not differ from isolated ACL reconstructions. The patient is encouraged to perform passive range-of-motion periodically throughout the day to nourish the healing articular cartilage and facilitate healing. Weight-bearing is delayed with either nonweight-bearing or toe-touch weight-bearing for the first 2–4 weeks, followed by 50% body weight in week 5–6, 75% body weight in week 6–7, and gradual progression to full weight-bearing by week 7–8.

The postoperative rehabilitation program for combined ACL reconstruction with ACI differs considerably. A period of precaution is used initially to allow healing of the chondrocyte implantation site. The patient is initially nonweight-bearing with the brace locked into extension for the first 2 weeks, toe-touch weight-bearing from week 3 to week 6, progressing to 50% body weight by week 6, and full weight-bearing by week 8. Similar to the microfracture procedure, passive range-of-motion is recommended periodically throughout the day to enhance healing. Patients often use a continuous passive motion (CPM) device at home for several hours a day for the first 2 weeks. Range-of-motion is progressed from 0° to 90° in week 2, to 0° to 105° by week 4, 0° to 125° in week 6, and 0° to 135° by week 8. Open kinetic chain exercises are performed initially and progressed to include closed kinetic chain, proprioceptive, and aquatic therapy by week 6. A gradual return to function is progressed and may include low-impact activities at 5–216 months, progressing to high-impact activities by 12 months.

Rehabilitation of the female athlete

Female athletes are more likely to sustain an ACL injury than male athletes [111–114]. In addition, the majority of these injuries are noncontact [29]. Several authors have shown this increased likelihood of female athletes suffering an ACL injury. Malone et al [114] reported that female college basketball players were eight times more likely to injury the ACL compared with her male counterpart. Lindenfeld et al [113] stated that female soccer players were six times more likely to sustain an ACL injury in comparison with male soccer players. There have also been similar data reported in other sports such as volleyball and gymnastics [111,112].

It appears that female athletes have some unique characteristics that may predispose them to injury. Because of the increasing number of women participating in athletics and their increased risk of sustaining an injury, we believe it is important that the female athlete undergo a specific rehabilitation program that addresses these predisposing factors.

Female athletes generally have a wider pelvis and increased genu valgum. Because a common mechanism of ACL injury is a valgus stress with rotation at the knee joint, it is important that the female athlete learn to control this valgus moment. Exercises designed to control this moment at the knee include front step-downs, lateral step-downs with resistance, and tilt board balance while performing a throw and catch. The athlete is given verbal instructions to control the knee from going into valgus during the lowering phase of a front step-down (Fig. 8). This moment can be increased through the use of a resistance band, thereby causing the athlete to resist the valgus force created (Fig. 9).

Huston and Wojtys [115] examined the muscular recruitment pattern to provide dynamic stabilization after an anterior tibial translation in male and female collegiate athletes and nonathletes. The investigators reported that male athletes and female nonathletes recruited their hamstring and gastrocnemius muscles first, whereas the female athletes contracted their quadriceps muscles to resist the anterior translation of the tibia. This appears to be a less efficient manner of providing stabilization to the knee and may cause an increase in ACL strain. The rehabilitation program should train the female athlete to stabilize the knee through coactivation of the quadriceps and hamstrings, as opposed to relying on the quadriceps for stabilization. To produce this response, the athlete performs dynamic stabilization drills with the knee flexed approximately 30°. It is important to emphasize flexing the knee to 30° to increase the activity of the quadriceps. Perry et al [33] reported on the electromyographic (EMG) activity of the quadriceps and found that at 15° of flexion, a 15% maximum voluntary isometric contraction occurred, and at 30° knee

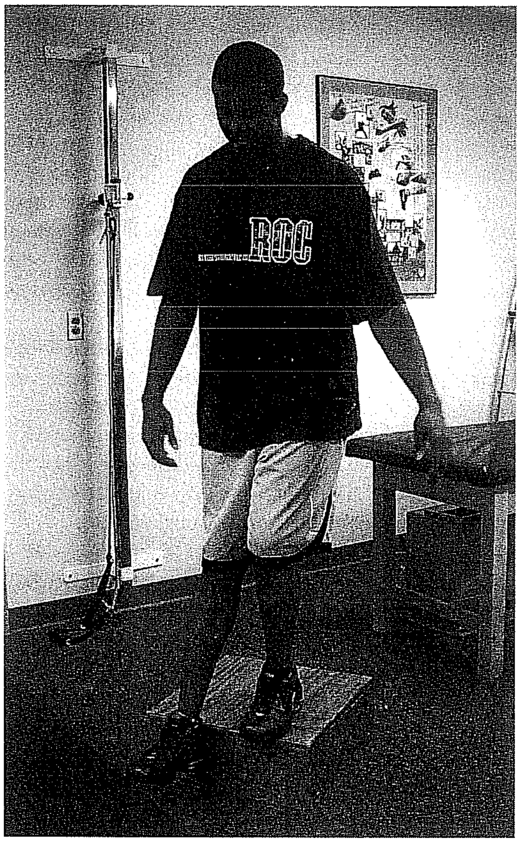

Fig. 8. Front step-down movement. During the eccentric or lowering phase, the patient is instructed to maintain proper alignment of the lower extremity to not allow the knee to move into a valgus moment.

flexion, EMG activity reached 51%. Neuromuscular control drills are performed at 30° knee flexion because this results in the highest amount of EMG activity of both the hamstrings and quadriceps (co-contraction) [54]. Exercises designed to provide cocontraction include lateral lunges with sport cord and squats on an unstable platform (eg, the Biodex Stability System™, Biodex Corp., Shirley, NY) (Fig. 10). These exercises teach the athlete to learn to maintain a flexed knee and dynamically stabilize the knee through cocontraction of the quadriceps and hamstrings.

Komi and Karlsson [116] have reported that it takes female athletes approximately twice as long to obtain 70% maximal voluntary contraction compared with males. Several authors have demonstrated a longer electromechanical response time in females compared with males [117–119]. Therefore, it is important to train female athletes at high speeds in order to improve their reaction times. This can be accomplished by performing isokinetic exercises (Biodex) at high speeds, side shuffles, running backward, and knee flexions performed at high speed with a resistance cord.

Female athletes should learn to control the hip and trunk in order to reduce the hip adduction and abduction that can occur when landing from a jump. Hakkinen [120] reported that the leg extensors, and the trunk flexors and extensors, in male basketball players were significantly stronger than those in female basketball players. The female athlete can improve core stability and hip strength through lateral step-overs [22] and dip-walking on a balance beam (Fig. 11). It is important to train the athlete to control these motions because female athletes commonly land following a jump with the hip adducted and the body falling laterally.

Several authors have reported that females generally have less muscular strength compared with male athletes [116,120,121]. Because of the less-developed thigh musculature, the rehabilitation program should contain exercises that strengthen the entire pelvic musculature to assist in compensating for thigh musculature weakness. A four-way hip

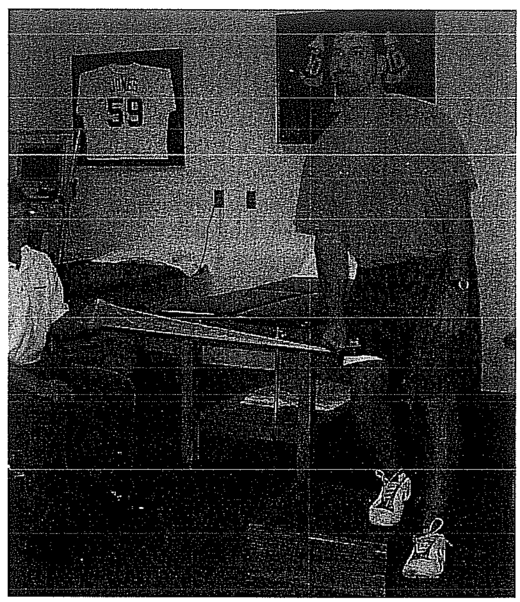

Fig. 9. Lateral step-down with theraband resistance. Theraband is applied around the inner knee to provide resistance to control the valgus moment at the knee.

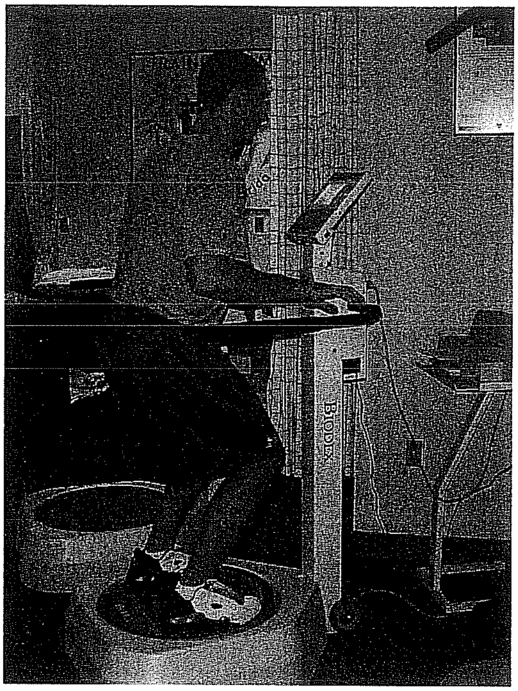

Fig. 10. Squats performed on the Biodex (Biodex Corp., Shirley, NY) stability system.

machine can be used, along with lateral step-overs and lateral lunges to train the thigh musculature.

Female athletes generally have increased range-of-motion and greater laxity than male athletes. Huston and Wojtys [115] reported that females have significantly more anterior tibial diplacement as compared with males (4.5 mm versus 3.5 mm). Females tend to land after jumping with increased knee extension and decreased hip flexion. The female athlete should learn to control this knee extension. Specific drills that can be incorporated include plyometric jumps on a leg press (Fig. 12), and plyometric jumps on flat ground and boxes. The athlete is instructed to land with the knee flexed at 30°. The emphasis during this exercise is on the athlete's landing. Other plyometric jumping drills that can be incorporated are scissor jumps and step jumps (Fig. 13). According to Hewett et al [70], male athletes demonstrate threefold greater knee-extension movement (hamstring muscle activity) than female athletes when landing from a vertical jump. In addition, they noted that, following an 8-week jump training program, there was a 22% decrease in peak landing forces in the female athletes.

The rehabilitation program is also aimed at increasing the females' ability to stabilize the knee dynamically. Wojtys et al [122] reported that males were able to contract the knee musculature and dynamically increase the stiffness of the knee joint by 473%, whereas females were able to increase the stiffness only by 217%. So it appears that females are not as efficient at providing dynamic stability to the knee. Perturbation training drills are employed to help train female athletes to learn this neuromuscular control of their lower extremity.

Muscle fatigue has also been shown to affect performance. Hakkinen and Komi [123] reported on EMG activity associated with fatigue following a maintained 50% of maximum isometric contraction. It was noted that there was a significant increase in EMG activity and a decrease in mean power. Zhou et al [124] showed an increase of 147% in the electromechanical delay of the knee extensors following muscular fatigue. Therefore, it is important to include endurance training for the female athlete [126].

Thus, it appears there are differences that exist between the male and female athlete, both anatomic and neuromuscular, that may predispose the female to

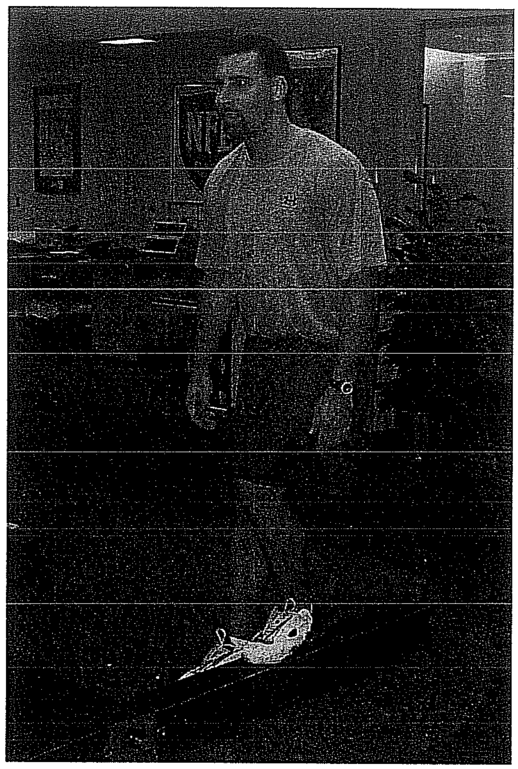

Fig. 11. Proprioceptive training drill: dip walk on the balance beam.

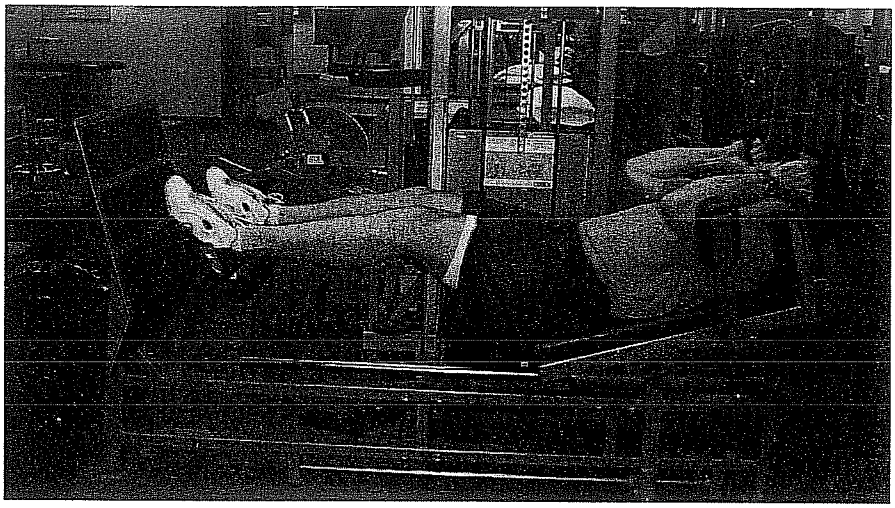

Fig. 12. Plyometric leg press: the patient is instructed to land with the knee flexed, and to absorb shock during landed.

an increased rate of ACL injury. It is important to examine these differences and prescribe an appropriate program to address these differences in order to allow for a complete and thorough rehabilitation process for the female athlete.

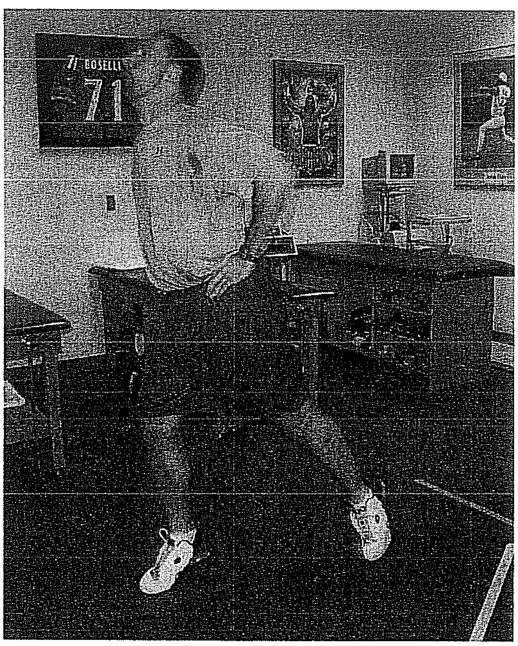

Fig. 13. Plyometric drill: scissor jumps.

Summary

The rehabilitation process begins immediately following ACL injury, with emphasis on reducing swelling and inflammation; improving motion; regaining quadriceps control; allowing immediate weight-bearing; and restoring full passive knee extension and, gradually, flexion. The goal of preoperative rehabilitation is to prepare the patient mentally and physically for surgery. Once the ACL surgery is performed, it is important to alter the rehab program based on the type of graft used and any concomitant procedures performed. This will aid in preventing several postoperative complications, such as loss of motion, patellofemoral pain, graft failure, and muscular weakness.

The goal of this article has been to provide an overview of the application and the scientific basis for formulating a rehabilitation protocol following ACL surgery. For an athlete to return to competition, it is imperative that he or she regain muscular strength and neuromuscular control in their injured leg while maintaining static stability. In the past, rehabilitation programs attempted to prepare the athlete for return to sports by using resistance exercise alone. Current rehabilitation programs focus not only on strengthening exercises, but also on proprioceptive and neuromuscular control drills in order to provide a neurologic stimulus so that the athlete can regain the dynamic stability needed in athletic competition. We believe that it is important to use this approach not only for a rehabilitation process, but also to address any possible causes that might predispose the individual to future injury.

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