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A history of post-operative rehabilitation after an ACL reconstruction

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**A HISTORY OF POST-OPERATIVE REHABILITATION AFTER AN ACL
RECONSTRUCTION**

A Thesis

Presented to

The Faculty of the Department of Human Performance

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

Diana Lynn Keith

December 1999

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1999

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Abstract

A History of Post-Operative Rehabilitation after an ACL Reconstruction

By Diana Lynn Keith

The anterior cruciate ligament reconstruction has become a very popular procedure that in the last 20 years has become the topic of a plethora of research. Rehabilitation after an ACL reconstruction has also been the focus of research in the last 10 to 15 years. Between 1917 and 1962 research and technology limited the surgical procedure and rehabilitation was almost non-existent. Rehabilitation in general was initiated and dictated by the patient's surgeon. Between 1963 and 1983 rehabilitation programs become more specialized and organized into phases based on time. Research and advanced technology increased knowledge and a greater understanding of the surgical procedure. From 1984 to the present day, ACL reconstruction has become a very common procedure, requiring a specific rehabilitation program geared at returning patients back to normal activities in the quickest and safest way possible.

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Chapter 1

Introduction

Many different injuries can occur in the knee joint, but the anterior cruciate ligament (ACL) rupture has been the subject of many studies and papers (e.g. Paulos, Noyes, Grood, & Butler, 1981, Schenck, Blaschak, Lance, Turturro, & Holmes, 1997). In conjunction with the injury itself, the ACL reconstruction has also gained the attention of many researchers (e.g. Burnett & Fowler, 1985, Veltri, 1997). There have been numerous studies on the post-operative rehabilitation following surgery over a span of many years (Paulos et al., 1981, Schenck et al., 1997). There has been a trend over the years toward more aggressive care after surgery. This study discusses the history of this post-operative rehabilitation after ACL reconstruction.

The knee is a hinge joint with a synovial capsule surrounding the articulations between the femur and the tibia, and the patella and the femur (Gray, 1974). Surrounding the capsule are various muscles, which also help to stabilize the joint (see Figure 1.1). Within the joint, two major ligaments give the knee stabilization, these are the ACL, which runs posterior to anterior and the posterior cruciate ligament (PCL), which runs anterior to posterior (see Figure 1.2). If either of these ligaments is partially or completely torn the stability of the knee is jeopardized. The ACL plays a significant role in stabilizing the knee during stress by preventing anterior tibial translation, according to its attachment sites from the femur to the anterior tibia (Arnheim, 1989). Planting the foot and applying a twisting force to the lower extremity or a direct blow to the knee are the actions that

usually rupture the ACL. ACL injury management differs according to the extent of the injury.

In 1895, Mayo Robson treated an injured miner who had an accident 1 year earlier while working in the coal mines (Mayo Robson, 1903). The patient showed symptoms of crucial ligament ruptures, and Mayo Robson repaired these ligaments by a surgical technique of suturing the ligaments to the synovial membrane around the knee. Three years later, in 1898, Battle also repaired a torn ACL by suturing the ligament back together (Battle, 1902). According to Hey Groves (1917), ACL and PCL ruptures were becoming more frequent because of World War I and the increasing injuries in soccer. He believed that surgical re-attachment of the ligament was not effective, so he perfected a procedure on cadavers before using it on a patient. Most complete tears of the ACL require reconstructive surgery for active patients (Bilko, Paulos, Feagin, Lambert, & Cunningham, 1986). On April 25, 1917 he completed his first surgical reconstruction of the ACL on a man injured by a horse kick. He used a muscle tendon to replace the ACL. Since this time, the surgical technique for ACL reconstruction has improved with each surgeon trying to find the best method and the most tensile material to replace the ruptured ligament. Three years later, Hey Groves (1920) had reconstructed 14 soldiers' knees trying to find the most effective means to replace the ACL. ACL injuries were becoming more prevalent with soldiers who were injured during World War I. After surgery, most patients were placed in a plaster cast covered by a splint for 1 month, then the cast was removed and replaced with a straight splint (Cubbins, Conley, Callahan, &

Scuderi, 1932, Mayo Robson, 1903). The patient would attempt range of motion (ROM) after 6 weeks then attempt to walk after 14 weeks (Cubbins et al., 1932). Historically, this type of care was common after a surgery in the past.

All reconstructions should have some type of rehabilitation after surgery (Brewster, Radovich Moynes, & Jobe, 1983). The long-term goal for an active person who has had an injury and subsequent reconstruction is to return to normal activities in the shortest amount of time (Timm, 1997). Medicine is a constantly changing profession as technology improves and as more is learned about the human body. Factors such as range of motion, when to bear full weight on the injured limb, immobilization, and time to return to activity have changed over the years (Shelborne & Nitz, 1990). Bilko et al. (1986) compared a rehabilitation program from 1980 to 1984 to investigate differences in the protocols, which they found had changed over the 4 year span. Results showed that there was a drastic difference in the angle of the knee during immobilization within this 4 year span. By the time this article was written, no physician was immobilizing the knee in less than 15 degrees of flexion, but in 1980 the knee was immobilized in as much as 60 degrees of flexion. Shelborne and Nitz (1990) also compared rehabilitation from 1984 to 1987, during which time they found dramatic changes in some of the aspects of rehabilitation. Some of their results showed that patients receiving care in 1984 to 1985 were not allowed to ambulate without crutches until 6 weeks after their surgery, whereas patients in 1987 through 1988 were allowed to ambulate without crutches, as they tolerated, on the first day after surgery.

Timm (1997) states that

current treatment processes produce better functional outcomes for patients in a shorter period of time, which also tend to be less expensive compared to older models of care. The evolution of ACL surgery and rehabilitation methods is reflected in patient outcomes; the expectation of return to unrestricted activity by 6 months, at most, without the need for a knee brace has replaced the old standard of 12-18 months in treatment along with the need to wear a motion-control brace during any type of high-demand physical activity (p. 43).

The protocols for post-operative care and rehabilitation have changed in these short amounts of time. The changes seen in a span of 80 years are likely to be significant.

Purpose of Study

The purpose of this study was to construct and review the history of post-operative care and rehabilitation after an ACL reconstruction, from the first ACL reconstruction in 1917 to the present day protocols. This thesis is not only a descriptive history, it is also analytical. Throughout the research, other topics were reviewed as they relate to the history of ACL reconstruction and rehabilitation such as history of arthroscopic surgery, history of rehabilitation, history of injuries in athletics, and the

history of physical therapy. It is important to learn about these topics as they relate to post-operative rehabilitation for the knee after surgery. In the course of the history, questions of why changes have occurred in the protocols are answered. The questions answered in this study are:

1. To identify by whom and when ACL reconstructions were done, and the surgical procedures used.
2. Identify what kinds of post-operative care and rehabilitation were used after the surgery.
3. Identify how the methods of post-operative care and rehabilitation have changed over the years;
  - 3a. Identify the role of immobilization and how this action has evolved in the face of ACL reconstruction.
  - 3b. Identify the changing opinions regarding range of motion and how much is allowed after ACL reconstruction.
  - 3c. Identify the changes regarding the appropriate time for ambulating after ACL reconstruction.
  - 3d. Identify the changes in the safest types of exercises used to rehabilitate the knee after ACL reconstruction.
  - 3e. Identify the changes in the time to return patients to full activity.
4. Identify why these changes occurred.

Delimitations

1. This study is delimited to the time period of 1917 to 1999. The first ACL reconstruction was completed in 1917 and from this time period until the present day the procedure has been changing.
2. Because the protocols for post-operative care and rehabilitation may remain unchanged for a certain period of time, this study only focuses on the time periods in which there was a change. The major topics which are likely to change will be range of motion, time to ambulation, immobilization, types of exercises used, and time period to return to normal activities.
3. The ACL reconstruction, according to the literature, can be completed with different graft materials. This study mentions the other materials used, but focuses on surgeries completed with the patellar tendon, semitendinosus tendon, gracilis tendon, and iliotibial band. These structures are mentioned as the most common replacement for the ACL in the literature.
4. Because there are possibilities of other problems associated with ACL tears, such as meniscal tears, this study only looks at material that deals exclusively with isolated ACL tears.
5. The ACL reconstruction can include intraarticular and extraarticular procedures. This study focuses only on intraarticular reconstructions.

Limitations

1. This study was limited to sources that were printed in the English language.
2. Because the history starts in 1917 and ends in 1999 and there is so much information, not every source about ACL reconstruction and rehabilitation written was used.

Only references that showed changes or differences from other protocols or previous years were used. If different authors used the same protocol, only one of the references was used.

Definition of Terms

Anterior Cruciate Ligament.

"The anterior cruciate ligament passes from the lateral intercondylar notch to attach anteriorly on the articular surface of the tibia and serves primarily to prevent anterior translation of the tibia"(American Academy of Orthopaedic Surgeons [AAOS], 1991, p.137).

Surgical Repair

"The damaged ligament is sutured if the tear is in the mid-substance of the ligament or the bony fragment is reattached in the case of an avulsion injury"(Davis & Prentice, 1994, p.408).

Extraarticular Reconstruction.

"Taking a structure that lies outside of the joint capsule and moving it so that it can affect the mechanics of the knee in a manner that mimics normal ACL function" (Davis & Prentice, 1994, p.408).

Intraarticular Reconstruction.

"Placing a structure within the knee that will roughly follow the course of the ACL and will functionally replace the ACL" (Davis & Prentice, 1994, p.408).

Patient

The patient is anyone who is injured during some regular activity such as competitive and recreational sports or a job related activity (AAOS, 1991, chap.1).

Rehabilitation.

The restoration of health in the area of physical disability, to its former state (Affeldt, 1969).

Isometric Exercise.

"The contraction of muscles without shortening or lengthening of the muscle fibers" (AAOS, 1991, p.980).

Isokinetic Exercise.

"Develops tension in the muscle as it shortens; performed on specialized machines or underwater" (AAOS, 1991, p. 980).

Isotonic Exercise.

“Contraction of the muscles concentrically or eccentrically against resistance with movement of the part” (AAOS, 1991, p. 980).

Closed Chain Exercise.

Exercise when the distal segment of the extremity is stabilized or fixed (Kahanov, 1998).

Open Chain Exercise.

Exercise when the distal segment is mobile, not fixed (Kahanov, 1998).

Arthroscopy.

A type of “surgery in which the interior of a joint is visualized through a scope attached to a camera”(AAOS, 1991, p.967).

Graft.

A structure either borrowed or artificial that is used to replace the existing torn ligament (Burnett & Fowler, 1985).

Allograft

Grafts between two or more individuals placed in one completely different host. (Medical Dictionary, 1997)

Autograft

Graft taken from one part of the body and placed in another site on the same individual. (Medical Dictionary, 1997)

Endoscope

An expensive and usually highly flexible viewing instrument with capabilities of diagnostic or even therapeutic functions through special channels. (Medical Dictionary, 1997)

Straight Leg Raise

An exercise in which the quadriceps muscles are contracted and the entire leg is lifted.

Significance of Study

With the frequency of new medical discoveries and advancement, the face of medicine is changing. Other aspects related to medicine must change as well.

Rehabilitation and post-operative care of injuries are important aspects that have changed over time. The ACL reconstruction management has been a subject of interest in the past and present, and likely will be in the future. By completing a history of rehabilitation and post-operative care for the ACL reconstruction, questions can be answered as to the reasons for the changes, such as technology, and new surgical techniques.

Chapter 2

Methodology

The purpose of this study was to research the history of post-operative care and rehabilitation after an ACL reconstruction from 1917 to the present day, and record major changes in the protocols and why those changes occurred. The major changes that were looked at closely were, range of motion, time to ambulation, immobilization, types of exercises used, and time to return to normal activities. This chapter includes the processes that were used to gather this information.

The information that was gathered consisted of both primary and secondary sources found mainly in books and journals on the subject of rehabilitation and post-operative care of ACL reconstructions. Searches were conducted on the Internet through PubMed, MEDLINE, and various on-line medical libraries. Any journal article titles and authors that referred to the ACL reconstruction were printed out. This was only a starting point. Once sources were found on the subject, the reference lists of those journal articles were used to find the earlier information on the subject. This "snowball effect" was used until the same references found in articles were found in other sources as well. Once a list of titles of articles and books was achieved, each reference was printed out on a 3" X 5" card with the complete bibliographic information. The cards were brought to the Stanford Lane Medical Library and the search for the articles was completed. Other libraries used were the San Jose State Library and the University of California at San Francisco Medical Library. After finding each article, a mark was made on the card as to whether the

reference was a usable source. By labeling each citation card with a good or bad symbol, it was easier to distinguish which sources were appropriate for the study.

Information on specific topics other than post-operative care and rehabilitation of the ACL were collected in the same manner as the topic of this paper. This information was used to explain the changes in protocols. The social aspects of the times can be motivating factors for change. The related topics included the history of physical therapy, the history of rehabilitation, the history of ACL reconstructive surgery, and the history of injuries in athletics.

Once all of the material to be researched had been included on cards and found in the library, the information was recorded by note taking and photocopying. Articles, which could not be found in the libraries at Stanford, SJSU, and UCSF, were obtained by inter-library loan. After all the references had been read and all of the notes had been taken, the information was organized according to year. Each year from 1917 on was grouped with other years in which the same protocol was used, and these years were included as one time period. The separation of time periods was based on the same format that was used in an article by Naranja, Corsetti, Kuhlmand, and Torg (1997). The time period 1917 to 1962 was chosen because in 1917 the first ACL reconstruction was completed and this was considered the early years for ACL management and research. The time period of 1963 to 1982 was chosen because the first ACL reconstruction completed with a patellar tendon, which contained bone still attached, was completed during this time and this was considered the “gold standard” for the substitution material,

and rehabilitation at this time was becoming more exercise oriented. It was after this surgery that the patellar tendon started to be used globally and was said to be the strongest material for substitution. The time period 1983 to the present day was chosen because in 1983 the first arthroscopically assisted ACL reconstruction was completed. Because of this surgery advancement, rehabilitation would become more accelerated. Once all of the data was recorded into each time period; a separate chapter for analysis was written to explain why rehabilitation changed.

The research was kept on the hard drive of the computer with a back-up copy. All of the research articles used as sources were kept in a metal filing cabinet.

Chapter 3

Time Frame: 1917-1962

The purpose of this study was to construct the history of post-operative rehabilitation after an ACL reconstruction from the first reconstruction in 1917 to the present day protocols. The specific sub questions that were studied were immobilization, range of motion, time to ambulation, specific exercises used to rehabilitate, and the time to return to normal activities. Before understanding the different opinions about the specific post-operative rehabilitation protocols for this span of 80 years, one must consider the surgery. Medicine has been changing with improved technology and what was once an experimental surgical procedure has become the topic of many books, research articles and conferences.

Surgical Techniques

The first reported ACL reconstruction was completed by Hey Groves in 1917. He performed an intraarticular reconstruction using the iliotibial band. The procedure consisted of a horseshoe incision made from medial to the lateral side of the knee, and then the patella was lifted up. He cut a strip of the tensor fascia lata and left the uppermost portion still attached and brought the band down through the joint by way of drilled tunnels in the femur and the tibia. The bottom portion of the band was attached to the tibia while the knee was in a fully flexed position. By 1920, Hey Groves had completed 14 reconstructions mostly on soldiers injured in the war, but only four were considered successful enough for the men to return to active duty. Hey Groves set the stage for others to use his procedure and to modify it. Smith (1918) used the same

procedure on two patients, and was the first to try using an artificial ligament. Forrester (1927) changed the procedure used by Hey Groves. He used two incisions, one on the lateral thigh down to the anterior knee, and the second longitudinal from the superior patella to the tibial tubercle. The patella was split to make the joint visible and the tibial and femoral tunnels were made in the same fashion as previously stated. The new ligament was taken from the fascia on the lateral side of the thigh, rolled and brought through the tunnels then sutured to a periosteous flap on both ends. Cubbins, et al. (1932) performed the identical operation using the vastus lateralis as the ACL substitute, and a medially based incision to make the joint visible. Campbell (1936) used a strip of fascia, capsule, quadriceps and patellar tendon brought up through the tunnels with a wire loop, and Macey (1939) used the hamstring tendon as the replacement of the ACL. During this same time others were attempting to regain stability in the knee by performing extraarticular reconstructions. Bennett (1926), Cotton and Morrison (1934), and Bosworth and Bosworth (1936) used free strips of the illiotibial band to either reinforce or reconstruct the medial collateral ligament. They believed that by doing this the knee was stable enough without an ACL.

Directions on treating the crucial ligaments were lacking (Palmer, 1937). There were controversies about the correct treatment to use, with some claiming that acute injuries to the ACL should be treated conservatively, but there was no research to prove that the torn ACL will spontaneously heal. Palmer (1938) wrote extensively on the ligaments of the knee, their function and injury. He stated that if operative treatment is used it should only be performed on the young and middle aged. He also stated that acute

ACL tears should be sutured back to the attachment site and chronic or complete tears should be substituted, but it was not recommended. Augustine (1956) stated that it was the opinion of others that the cruciate ligaments were of lesser importance than other ligaments of the knee, and that quadriceps strength alone was enough to stabilize the joint. He also stated that the crucial ligaments are the principal sustaining ligaments of the knee and acute injuries will benefit from repair but chronic injuries need to be substituted. O'Donoghue (1959) was the first to state that surgical repair is most successful if done in the acute stage. He also stated "late reconstruction is highly speculative and should be done only when the stakes are high, as, for example, a professional baseball player who is unable to play because of anteroposterior instability" (p. 1428). By the 1960s, most kinds of ACL reconstruction were being tried but there were still some controversies regarding which material used for substitution would give the best result.

Rehabilitation

While rehabilitation after an ACL reconstruction has been the discussion of many researchers in the past 20 years, the information during the time period of 1917 to 1962 is somewhat lacking. The term rehabilitation did not even exist in print until the 1950s (Licht, 1970). Research during this time was limited to general rehabilitation of all knee injuries, acute injuries treated with surgical repair, and a small amount of research on rehabilitation after an ACL reconstruction.

Early history explains that a patient's total care was under the responsibility of the physician to the best of his ability (Affeldt, 1969). During World War I, surgeons were

beginning to specialize in bone and joint surgeries and implementing physical therapy into their practices (Aldes, 1967). Rehabilitation began to surface in World War I and increased in World War II in both military and civilian hospitals. Only those patients who presented pain and instability for months to years after initial injury were even considered for reconstruction as a last resort. "Treatment of ruptured crucial ligaments should consist of absolute rest, and under no consideration whatever should active or passive movements be restored until from two to four months have elapsed" (Jones & Smith, 1913, p. 87). Jones and Smith stated that all patients should be put into a splint of some kind while the leg is in full extension and the splint should be worn at all times for 3 to 6 months. Once the injury healed the patient was put into a jointed splint to allow 20 degrees of flexion which could be increased gradually with massage. Forrester (1927) and Palmer (1938) also believed that acute ACL tears should be treated conservatively. Forrester (1927) placed his patients in a plaster cast with the knee in 20 degrees of flexion for 2 months, followed by another 6 to 8 weeks in a knee cage. During this time the patient was allowed to start active and passive range of motion. The patient was not allowed to put weight on the knee for 4 months. The patient began exercises for the quadriceps, which consisted of isometric tightening of the muscle while the knee was in full extension and, while in the knee cage. A patient with this type of injury was able to return to work in 5 1/2 to 6 months. Palmer (1938) suggested that the patient should be put into a plaster cast for 5 to 8 weeks followed by active gymnastics when the cast is removed. He also stated that the patient should do straight leg raises (SLR) while in the cast. O'Donnell (1940) published what he called "general knee treatment" for a variety of

knee injuries, including the ACL. The program consisted of cold compresses for 1 to 2 days; after the third day massage was started to decrease effusion in the hamstrings and the quadriceps. After 1 week to 10 days, active or active assistive motion could be initiated followed by resistive extension and flexion. The patient would use crutches to ambulate until the doctor allowed him or her to walk without them. O'Donnell suggested adding more exercises to the rehabilitation program such as hip adduction, abduction and resistive hamstring exercises until the circumference of the injured thigh was equal to the uninvolved leg. Later, O'Donnell (1944) published a more complete list of exercises for rehabilitation of the knee with a simple progression.

Acute tears of the ACL that were not treated conservatively were treated with surgical repair. O'Donoghue (1950) stated that early repair is good and will elevate the need for reconstruction later. In 1959, he stated that "It has been shown through years of observation, however, that nonsurgical treatment is not always the best treatment"(p. 1424). Post-operative care for O'Donoghue (1950, 1959) consisted of placing the knee in a plaster splint with the knee in either 20 or 30 degrees of flexion for 4 weeks, followed by an additional 2 weeks in a cotton cast. His patients were put on crutches, and were told not to bear weight for 4 weeks (O'Donoghue, 1950, 1959). At 3 days after surgery his patients were encouraged to begin quadriceps setting, SLRs, and quadriceps exercises were allowed at 6 weeks. Quadriceps exercises consisted of knee extension with no resistance initially then progressing with resistance to 25 or 30 pounds (O'Donoghue, 1959). Other exercises his patients were encouraged to complete were going up and down stairs, double and single knee bends, and running was permitted as desired.

Rehabilitation was continued until the thigh circumference was equal to the uninvolved leg and athletes were allowed to return to contact sports after 4 months. O'Donoghue (1950) stated that the majority of his patients required ACL reconstruction later. Brenner and Klein (1962) conducted a study on the effect of exercise on post-operative knee cases. Brenner and Klein stated that although surgery was considered successful, patients felt considerable functional insecurity especially because it prevented them from enjoying a return to physical participation. They took two groups of patients who had received knee surgery and put them through exercise programs to decrease strength imbalances between involved and uninvolved legs. "With the broad national concern and interest in this problem of knee injury, in athletics as well as industry, it seems that post-operative exercise programs leading to total rehabilitation will soon be more fully utilized" (p. 686).

During this time period the general consensus was that only in knees with chronic ACL tears or after all other treatment has failed should reconstruction occur. The post-operative rehabilitation for patients who had a reconstruction was not much different from that after a repair or conservative treatment of non-operated knees. Forrester (1927) placed his patients in plaster casts with the knee in 20 degrees of flexion for 6 to 8 weeks. Once the plaster cast was removed the patient was placed in a knee cage and instructed to complete quadriceps exercises for 2 to 3 months. Forrester mentioned a patient of his that returned to work 3 ½ months after surgery. His patient had full knee extension but was limited to just past 90 degrees of flexion. Cubbins et al. (1932), had patients put into plaster splints with the knee in 25 degrees of flexion for 4 weeks then replaced these

with straight angled Thomas splints. For the next 6 weeks the patient was allowed to start passive range of motion eventually beginning active range of motion. The patient was allowed to start walking with a brace at 14 weeks post-operatively but there was no mention of any exercises. O'Donnell (1935) published an extensive post-operative and rehabilitation program that he had used for the past 8 years in which his patients were able to return with full use of the knee without a brace. After surgery the knee was immobilized in a plaster cast for 3 days, on the fourth day the cast was replaced with elastic bandages and felt strips. On the fifth post-operative day, light massage above the quadriceps, and quadriceps setting was started. By the ninth day the patient was able to get up on crutches and gradually increase weight bearing. Active knee extension was started in a limited range and by the tenth day the patient was discharged from the hospital. During the next 2 weeks massage to the quadriceps and hamstrings continued to increase active and passive range of motion, and quadriceps sets, SLRs and active assistive knee flexion were implemented. The patient, at this time, was ambulating with partial weight bearing and increasing to full weight bearing. During the third week active motion increased and the patient started seated knee extension exercises in limited ranges, gradually increasing resistance. Knee extension and flexion exercises continued gradually increasing resistance while stationary bicycle riding started in the third week and use of the rowing machine in the fourth week. During the fifth week the patient was allowed to start jogging and running in a straight line and weight bearing exercises such as deep knee bends were implemented. Between 8 and 12 weeks the patient was allowed to complete any exercises and continued this program until the thigh circumference of the

injured leg was equal to that of the uninjured leg. O'Donnell did not mention the actual time period when his patients returned to work or physically demanding activities.

Other researchers during this time frame did not publish rehabilitation programs which their patients used but placed a greater importance on immobilization after surgery. Campbell (1936) reported 17 cases of ACL reconstruction, nine with excellent results. Patients were placed in a posterior splint, with the knee in 140 degrees of flexion, for 3 weeks after which active and passive motion were started. He stated that nine college football players returned to competition in 6 to 10 months after surgery. Cubbins, Callahan, and Scuderi (1937b) reported that after four ACL reconstructions, patients were immobilized with the knee in 25 degrees of flexion for 1 month then in full extension for another 3 months. Cubbins et al. mention that biceps femoris atrophy was a complication but that they relied on the strength of the ligaments for a complete recovery. Cubbins, Callahan and Scuderi (1937a) published a case report of a 19-year-old patient who injured his knee while playing football. After ACL reconstruction, the patient was placed in a cast with the knee in 35 degrees of flexion for 4 weeks. Passive motion and massage were instituted at 8 or 9 weeks post-op and at 12 to 16 weeks the patient was walking with crutches. At 6 months the patient was walking without any supportive device and returned to work at 9 months. Palmer (1937) gave a list of various patients who received ACL reconstructions and the amount of time they were immobilized. A 68 year old coal heaver and a 20 year old warehouse laborer were both put in plaster for 6 weeks, and a 44 year old chimney sweep was put into plaster for 8 weeks and able to complete range of motion after 4 weeks. Augustine (1956) stated that his patients were put into a plaster

splint for 3 weeks with partial weight bearing allowed, then vigorous physical therapy was initiated, but he did not publish this therapy.

Although it was important to strengthen the injured knee to return to normal activities during this time frame, research did not specifically discuss what types of programs should be used, a subject that would increase as time went by. Anterior cruciate ligament reconstruction and rehabilitation research was just starting to emerge as an important topic that needed to be studied more. Information during the time period of 1917 to 1962 was very limited and very general. The next years of study would be crucial to the success of patients with a torn ACL.

Chapter 4

Time Frame: 1963-1982

During the early 1960s to the early 1980s surgical treatment for a torn ACL was becoming more important to physicians and they were exploring the different possibilities that could make the treatment better. Surgical reconstruction was becoming more effective and the physiology of the knee was better understood. There were still those during the 1960s who believed that an ACL reconstruction should only be used as a last resort. Rehabilitation was still not considered as important as getting the correct surgical procedure. Rehabilitation programs were still very general and not specific to ACL reconstruction. Exercise was becoming more important after any knee injury or surgery and researchers were beginning to construct exercise programs for anyone who suffered this type of injury.

Surgical Techniques

O'Donoghue (1963) had tried many different techniques, developed by Hey Groves (1917), Campbell (1936) and Augustine (1956), finally using a modified Hey Groves' technique. However, the majority of his patients did not improve. The most prevalent complaints by his patients were restriction of motion and stability (O'Donoghue, 1963). Jones (1963) developed a new surgical procedure for the ACL reconstruction, which he said could be used for both acute and chronic ACL instability. He used the central 1/3 of the patellar tendon with its bottom portion still intact and a wedge of the patellar bone, lifted up over the tibial edge and inserted into an anterior tunnel in the lateral condyle of the femur. According to Burnett and Fowler (1985), in

1968, Lam modified this technique by using the medial 1/3 of the patellar tendon with a bone block and a screw. He placed the new ligament in a more anatomically correct position, and rotated it 360 degrees to duplicate the spiral effects of the normal ACL. Jones (1970) changed his procedure by utilizing only one incision and used a bone block and a pin, which went through both condyles of the femur to hold the bone block in place. According to Burnett and Fowler (1985), Jones only had 19 of his 46 patients returning to athletics and 17 were restricted in their daily activities due to postoperative problems such as restricted motion.

During the 1970s there was interest in treating specific types of rotatory instabilities in ACL-deficient knees using mostly the iliotibial band and extraarticular reconstructions (Burnett & Fowler, 1985). Long term studies of patients with ACL-deficient knees showed progressive knee deterioration and a functioning ACL was found to be critical for lasting function of the knee, therefore ACL reconstruction was recommended, and intraarticular procedures using the patellar tendon were revived in the 1970s. Alm and Gillquist (1974) used the medial portion of the patellar tendon left attached to its tibial attachment. They drilled the tibial and femoral tunnels in the same spots where the original ACL attached, then brought the substitution ligament through the tunnels and attached it with sutures to the lateral surface of the femur. In Sweden, Eriksson (1976) described using arthroscopy to diagnose ACL tears with a 96% accuracy. Eriksson believed that acute tears should be sutured to their femoral attachment and criticized American orthopedists for not repairing the ACL. The Swedes only reconstructed the ACL in chronic cases, and used the Jones procedure with a bone plug

on the patellar tendon. The Swedes used a drill guide to improve anatomic positioning (Burnett & Fowler, 1985). According to Burnett and Fowler (1985), Franke was the first to describe a free transplant of the patellar tendon with bone from the patella and the tibia.

Through the early 1980s, more and more literature was being written on the ACL, its function, diagnosis, and management. Old surgical techniques were being refined, and more thought was given to placement and tissue types for the substitute. "With the modern era of anesthesia, aseptic technique, roentgenography, antibiotic therapy, increased longevity, motor vehicles and professional athletes, the ACL has emerged to the forefront of orthopedic concerns" (Snook, 1983, p. 11). Researchers were stressing precise placement of the intraarticular graft, the use of drill guides, intercondylar bone resection and new fixation techniques (Burnett & Fowler, 1985).

Rehabilitation

During the 1960s, research on rehabilitation after an ACL reconstruction was still lacking since the actual surgery was still used as a last resort. Rehabilitation as a whole was still evolving in the medical field. "Since orthopaedic surgery began to emerge as a specialty, the influence of the muscles on the form and development of the human body has been considered paramount" (Trueta, 1963 p. 347). Rehabilitation was starting to be considered important for not only athletes after injury but also lay people. Nichols (1969) suggested that heavy laborers who have been injured should have a period of intensified rehabilitation to get them back to work.

There were still some in the medical community who believed that a torn ACL could either be treated conservatively or by surgical repair. Stewart (1961) placed his patients in plaster after surgical repair. The patients completed exercises such as quadriceps sets, SLRs, knee extension and knee flexion exercises during rehabilitation. Athletes who played tennis or basketball were allowed to return to activity after 4 months, those who played football or baseball returned after 6 months. Helfet (1963) stated that intraarticular procedures such as ACL reconstruction have no special indications or merit. Helfet treated his patients with repair if the ACL was torn from its inferior attachment site. Post-operative care for his patients consisted of immobilization in a plaster splint for 2 weeks followed by ambulation on crutches with the knee in a back splint. Quadriceps sets were started after 2 weeks, then active flexion exercises started after 3 weeks. At 6 weeks the patient was allowed to ambulate without crutches but with the splint, and at 8 weeks the splint was removed. There was no mention of any of the exercises, if any, that were used to rehabilitate his patients.

During this time exercise programs were starting to be developed and becoming an important part of the rehabilitation process. According to Prentice (1990), DeLorme developed one of the first strength training programs in 1951. This program was based on the amount of weight that can be lifted 10 times. The weight lifted was based on the maximum amount the patient was able to lift in one knee extension; this was referred to as their one repetition maximum (1RM). It was this program that many were using when rehabilitating the knee after surgery. "The role of exercise in medical rehabilitation is of greater importance than all other measures employed in this sector, singly or combined"

(Jokl, 1964 p. 16). Brueckman (1962) suggested patients after surgery should be in a stirrup splint for 3 days, during which they should perform quadriceps sets, followed by 5 weeks in a cylinder cast, during which the patient performed SLRs. He recommended no forced flexion prior to 3 months and progressive resistive exercises may start after this time period. He used a progression with exercises as follows: When quadriceps sets can be performed 50 times without pain the patient starts performing SLRs, when the patient has been able to complete SLRs 50 times he or she is able to start knee flexion exercises to 90 degrees. When the patient is able to achieve a range of 0 to 90 degrees with no problems, 2 pounds are added to the exercise and increased accordingly. This exercise continues until a high school patient can lift 25 pounds 50 times, or a college student can lift 50 pounds 50 times. Donoho and Rylander (1966) developed a general plan for rehabilitation of a sprained knee. They indicated that a severe sprain of the knee needs to be immobilized in 15 degrees of flexion and surgery is indicated, but there was no exercise plan for after surgery. They recommended progressive resistive exercises the day after the injury occurred for the hamstrings and quadriceps, and returning to play when the athlete can lift 50 to 60 pounds during knee extension 10 times. Davies and Thompson (1967) developed a general rehabilitation program for the knee that was most likely meant for a knee injury before surgery is indicated. Before the rehabilitation could start the patient should have full range of motion and be able to complete SLRs in all four directions, and complete isometric quadriceps sets in 90, 45, and 5 degrees of knee flexion. Rehabilitation consisted of knee extension exercises three times a week, in a three set system of 50%, 75%, and 50% of their one repetition maximum lifted 10 times.

Other exercises included hip flexion, knee flexion, isometric flexion and extension, leg press, hip abduction, and toe raises. A running program with progressions consisted of jogging 200 yards, 10-yard sprints, moving on to running a “S” pattern and concluded with running steps and circles. Klein and Allman (1969) discussed rehabilitation following different knee injuries based on the DeLorme principals. They stated that the hamstrings were a vital part of the knee mechanism and largely responsible for the lateral stability and rotary movements of the knee. All of their programs were based on the 1RM. Three sets of exercises are completed for the quadriceps and hamstrings, and the hamstrings should be exercised at 50 to 60% of the quadriceps strength. Yamamoto, Hartman, Feagin and Kimball (1976) did not discuss specific rehabilitation for surgical verses nonsurgical knees, they developed a general rehabilitation program for all knee injuries. Their rehabilitation program consisted of progressive resistive exercises to restore muscle bulk and strength based on the DeLorme principal. They also developed an exercise program to increase agility function. Although these exercise programs were not specifically for ACL reconstruction rehabilitation, they started the general consensus that exercises were needed as well as post-operative care after knee surgery.

Post-operative care and rehabilitation after an ACL reconstruction still had not become a general program that every surgeon and therapist adhered to, each was still setting up programs on an individual basis. O'Donoghue (1963) immobilized his patients for an 8-week period, during which there was no weight bearing allowed for the first 2 weeks, then partial weight bearing for 4 weeks and finally full weight bearing the last 2 weeks. During this 8-week period, exercises such as quadriceps sets, SLRs in all

directions and calf raises were allowed. Once this 8-week period of immobilization was over, motion was allowed in the knee, and once motion allowed, the patient was able to run or jog. The patient was allowed to return to competitive sports when full range of motion was achieved and the involved quadriceps were as strong as the uninvolved side. Jones (1963) immobilized his patients for 4 weeks in 10 degrees of knee flexion after which range of motion with whirlpool baths and passive exercises with resistance were begun. The patient was able to walk without the use of crutches between 6 and 8 weeks and continued exercises on their own until they regained maximum knee flexion and maximum strength, which could take up to 6 months. In 1970, Jones immobilized his patients in a plaster cylinder with five degrees of knee flexion for 6 weeks. The patients completed physical therapy at home on their own. By 2 months post-operatively, they should have had increased their quadriceps strength and a range of motion from 0 to 90 degrees and by 6 months post operatively, his patients had a range of motion of 0 to 65 degrees. Jones stated that most of his patients would lose 10 to 15 degrees of flexion but should be able to gain full extension. Alm and Gillquist (1974) immobilized their patients in a plaster cast for 4 weeks with the patients completing quadriceps sets while in the cast. Once the cast was removed the patient began range of motion and exercises for the quadriceps. After 2 months patients were allowed to begin running and cycling, and able to return to normal activities with no restrictions after 4 months. Out of all their patients who received ACL reconstruction and used this protocol, only 66% resumed athletic activity. Although Eriksson (1976) only reconstructed a few cases of ACL injury, his patients were immobilized in a mobile cast brace with motion allowed from 20

to 60 degrees of knee flexion. Patients completed SLRs and quadriceps sets for strength. Steadman (1979) wanted his patients to avoid knee extension beyond 45 degrees so his patients were immobilized for 8 weeks then an additional 4 weeks in a cast brace with motion from 90 to 45 degrees allowed. Range of motion was continued after this 12-week period and weight bearing was allowed without crutches. Exercises consisted of SLRs in 45 degrees of knee flexion for all four motions. Knee extension exercises were limited to 45 degrees of knee flexion for 6 months but knee flexion exercises were unlimited. Other exercises such as stationary bicycle and running were allowed as range of motion increased, eventually adding side to side hopping and cutting. The patients were required to wear a brace for up to one year after rehabilitation was completed. Although post-operative care and rehabilitation had still not become a globally accepted practice, small advances in the development of post-operative programs were beginning to occur. It was becoming clear to many that more research was needed to give the patients the best chances to recover from this increasing problem.

During the early 1980s, there were many changes in the rehabilitation after ACL reconstruction. Rehabilitation programs after ACL reconstruction were becoming more specific instead of the general programs of the past. Each was setting specific goals to be achieved and rehabilitation started being divided into phases based on the tissue healing time for the ACL graft. There was still disagreement among physicians regarding the safest and most effective way to rehabilitate the ACL reconstructed knee, so there was still not an accepted protocol that everyone was using.

Paulos et al. (1981), created five phases to their rehabilitation program which consisted of: The maximum protection phase, moderate protection phase, minimum protection phase, return to activity, and activity and maintenance. Each of these five phases consisted of two more periods, based on the minimal time needed, and specific goals were to be achieved during these periods. The maximal protection phase lasted for 12 weeks, and was divided into the early healing period and the controlled motion period. During the early healing period, which lasted from 4 to 6 weeks, there was maximum control of external forces and no motion was allowed. The leg was cast in 30 to 60 degrees of knee flexion and there was no weight bearing allowed. The only exercises permitted were isometric quadriceps and hamstrings on the operated leg and exercises on the opposite leg and upper extremity. Paulos et al. completed ACL reconstruction with a patellar tendon as the graft material; they believed that tissue healing strength and remodeling of the graft did not take place until at least 24 weeks after surgery. They completed a study on dogs, in which the ligament was very weak (only 50% of maximal strength), at 12 weeks post-operatively, and for this reason they did not allow patients to have any forces on the knee. During the controlled motion period, which lasted 4 to 6 weeks, the knee was placed in a cast brace, which allowed motion from 30 to 60 degrees of flexion. Each week five degrees of extension and 10 degrees of flexion were added until the patient reached motion from 15 to 90 degrees of flexion. Weight bearing with toe-touch only was allowed and exercises consisted of hamstring isotonic and assisted extension, for motion only. During this period, Paulos et al. were still concerned with controlling external forces on the knee but they also allowed motion to nourish cartilage,

decrease fibrosis, and stimulate collagen healing. They allowed hamstring isotonic exercises because they did not create an anterior drawer force on the tibia. Phase 2 was the moderate protection phase which was further divided into the crutch-weaning period, from the 12th through the 16th post-operative week, and the walking period, from the 17th through the 24th post-operative week. During the crutch-weaning period the cast brace was removed and the patient was allowed to start increasing active range of motion and partial weight bearing with crutches. Isotonic exercises for the quadriceps and hamstrings were begun to strengthen the leg enough to bear weight. Leg extension exercise resistance was limited to 15% of the body weight, and knee flexion resistance was limited to 10% of the patient's body weight. Full weight bearing began around the 16th post-operative week if there was no swelling, range of motion was at least 10 to 80 degrees of knee flexion, quadriceps strength was equal to 15% of body weight and hamstring strength was equal to or greater than the quadriceps. During the walking period, motion was unrestricted and weight bearing was full with a brace. Isotonic exercises were continued for the quadriceps and hamstrings with a limited range. Activities such as light swimming and cycling were implemented to enhance cardiovascular and neuromuscular function. The minimum protection phase was divided into the protected activity period and the light activity period, which lasted from the 24th to the 36th post-operative weeks. During this time Paulos et al. stated that because of continued collagen maturation this phase required guarded increases of external forces, muscle strength, and coordination to enhance functional stability. Exercises in this phase were to develop a gradual-strengthening program for the major muscle groups, with the

same restrictions used in earlier phases. There was no running or jumping allowed and a brace was to be worn at all times. Towards the end of the phase isokinetic exercises for endurance were allowed. At about 9 to 12 months after surgery the return to activity phase began starting with the advanced rehabilitation period. This period was meant to achieve maximum strength, endurance and neuromuscular function, all exercises were accelerated and a de-rotation brace was worn during activity. Once the affected leg achieved muscular strength equal to 75% of the normal leg, there was no swelling present and range of motion was normal, the running period began, which lasted 6 to 12 weeks. At one year post-operatively, the activity and maintenance phase began, which included sport specific activities leading up to returning to full sport activities with a brace and strength training three times a week to maintain strength. Paulos et al. stated that they based this rehabilitation program on preliminary research and that the program would probably change with more studies.

By the end of 1982, the rehabilitation was becoming more specific with certain phases based on the healing time of the ACL tissue. More studies were focusing on the healing time for tissue after trauma, the specific biomechanics of the knee, and the effects of certain activities on the healing ACL graft. These questions that needed to be answered set the path for the future of ACL rehabilitation.

Chapter 5

Time Frame: 1983-present day

Major changes in the way ACL reconstruction was to be completed and technological advances during the early 1980s through the 1990s have brought ACL reconstruction to new levels. Research conducted on tissue healing, graft placement, and accelerated rehabilitation were the most important advances during this time period.

Surgical Techniques

Bilko et al. (1986) created a questionnaire to be given to orthopedic surgeons regarding current trends in repair and rehabilitation in ACL injuries. Of 50 questionnaires, 44 were returned, and most surgeons responded that they did not see most patients with an ACL tear within the first 24 hours of injury. Of the 44 respondents, 32 indicated that they performed ACL reconstruction on most of their patients, in which the patellar tendon was the material of choice in substitution followed by the semitendinosis, and the iliotibial band. Freidman et al. (1985) stated that the indications for a ACL reconstruction were: "Functional disability in patients unwilling to alter athletic lifestyles, patients who are having symptoms with activities of daily living, and failure after 6 months of rehabilitation" (p. 9). In the 1980s, the use of prosthetic ligaments to replace the ACL was a procedure that physicians were attempting. Some of the materials being studied included Dacron, Teflon, polypropylene, carbon and Gortex (Burnett & Fowler, 1985). Dahlstedt, Dalen, and Jonsson (1990) compared results of patients with either a reconstruction with Gortex or 1/3 of the quadriceps tendon, prepatellar tissue and patellar tendon. Their results showed that the Gortex patients had

more instances of pain and effusion. By the end of the 1980s, research into ACL reconstruction was common. Burnett and Fowler (1985) stated that arthroscopic repair and augmentation was going to be the technique of the future.

During the 1990s, surgical techniques for the ACL reconstruction were becoming standard, but with use of different substitution materials. There have been many debates on whether to use autografts or allografts, the patellar tendon or the semitendinosis, and whether surgery should be done by open procedure, arthroscopically assisted or endoscopic technique. The patellar tendon has been referred as the “gold standard” for the ACL reconstruction (Fu & Schulte, 1996). The advantages of the patellar tendon are its high tensile strength and its bone to bone healing; the disadvantages are patellofemoral pain from the autograft donor site, patellar tendonitis, and weakness in the quadriceps. The hamstring tendons are also commonly used as substitutes for the ACL, and the advantage to the hamstring tendons such as the semitendinosis is there is less pain at the donor site but the disadvantages are that it is not as strong as the patellar tendon, and there is a longer time for soft tissue to bone healing. Veltri (1997) suggests using a combined semitendinosis/gracilis graft for acute tears from the femur, and bone-patellar tendon-bone autografts for the remainder of acute and all chronic tears of the ACL.

There is a difference of opinion as to whether to use autografts, patient donors, or allografts from cadavers. Advantages to allografts are decreased pain, decreased operative time, improved cosmesis, and unlimited graft supply (Fu & Schulte, 1996). The disadvantages of allografts are possible disease transmission, a decrease in strength due to the sterilization techniques, and increased cost. Shelton, Papendick, and Dukes

(1997) conducted a study in which they compared the results of patients after having ACL reconstruction with either patella bone-tendon-bone allograft or autograft. Their results showed no differences in pain, swelling, anterior tibial translation with an arthrometer, and range of motion.

The biggest changes for the ACL reconstruction during the 1990s were the way the surgeries were being completed. The arthroscope and endoscopic techniques were becoming popular among surgeons. By 1992 arthrotomy had been replaced by arthroscopy (Meystre, 1992). The arthroscope is used by a medial incision to remove the graft and drilling the tibial tunnel. In an intraarticular reconstruction and an extraarticular augmentation with the semitendinosis tendon, a lateral incision is made for the fixation of the graft and drilling of the femoral tunnel. "The advantages of arthroscopically assisted ACL reconstruction include elimination of capsular incisions, decreased trauma to the fat pad, avoidance of desiccation of the articular cartilage, better visualization of the femoral attachment site, and lower incidence of postoperative patellofemoral pain than with open reconstruction" (Fu & Schulte, 1996, p. 20). Clasby and Young (1997) stated that arthroscopically assisted procedures are more technically demanding than open ACL procedures but they are less invasive and allow the patient a more rapid postoperative rehabilitation program.

Recently a single incision arthroscopic or endoscopic, as it is called, reconstruction has been advocated (Fu & Schulte, 1996). The advantages to endoscopic reconstruction are avoidance of a lateral incision. Harner et al. (1994) stated the potential benefits to be faster rehabilitation and less pain. The major disadvantage of endoscopic

techniques is that they are technically demanding (Veltri, 1997). O'Neill (1996) conducted an experiment comparing the results of three different techniques of ACL reconstruction. The three techniques were a two-incision technique with a semitendinosis-gracilis graft, a two-incision technique with a patellar tendon graft, and a single-incision technique with a patellar tendon graft. Reat and Lintner (1997) also studied the difference between one versus two incision ACL techniques. Both studies found no significant differences between groups (O'Neill, 1996, Reat & Lintner, 1997).

At the present time there is still no evidence to indicate which surgical procedures are the best. Veltri (1997, p. 124) states "because there are a variety of techniques for ACL reconstruction that have shown clinical success, the individual surgeon must use the technique that he or she is best able to perform to achieve reproducible knee stability". As surgical techniques improve and become more refined, patients can theoretically return more quickly (Harner et al., 1994).

Rehabilitation

During the late 1980s and the 1990s, technology began to improve along with research of the healing tissues and the effects of different factors such as immobilization and continuous passive motion. Immobilization in a plaster cast would soon be discarded with a cast brace that allowed some early-restricted range of motion. A new type of surgery, the arthroscopically assisted ACL reconstruction, also had an effect on rehabilitation.

Rehabilitation programs in 1983 emphasized no knee extension beyond 45 degrees for a selected period of time to protect the healing ACL graft. Steadman (1983)

suggested keeping the leg immobilized in a cast or cast brace with allowable motion from 45 degrees of extension to a maximum of 90 degrees of flexion for a total of eight weeks. Brewster, et al. (1983) required that patients should be put into a cast in 35 to 45 degrees of flexion for 4 to 6 weeks, because the greatest ACL tension is from 30 degrees to full extension. Extension is limited to 45 degrees for up to six months but flexion is allowed as the patient tolerates after the initial eight weeks according to Steadman (1983).

Brewster et al. (1983) allowed flexion increases as tolerated after four weeks, when the patient was wearing a cast brace, and increased extension 15 degrees at 10 weeks, at 15 weeks and achieved full extension by 18 weeks. Curl, Markey, and Mitchell (1983) allowed protected motion during the early healing phase of rehabilitation from 30 to 60 degrees, gradually increasing motion up to 15 degrees of extension and at least 90 degrees of flexion by the late healing phase. Brewster et al. (1983) allowed patients to start ambulating at 10 weeks after the operation, stating that early ambulation would create stress to the repair. Steadman (1983) allowed patients to start ambulating at 12 weeks after the operation, to allow them to regain some strength and range of motion. Exercises allowed during the first 10 weeks after surgery included knee flexion, hip abduction, hip extension, isometric hip adduction, quadriceps sets in 45 degrees of knee flexion and wall slides for range of motion (Brewster et al., 1983). Steadman (1983) allowed leg lifts in a bent knee position in all quadrants during the eight weeks of immobilization, and well leg exercises were performed to continue strength in the uninvolved limb. Both Steadman (1983) and Brewster et al. (1983) allowed short arc quadriceps around 11 or 12 weeks after surgery but still limited extension to 45 degrees.

Exercises were continued as range of motion allowed and as the patient began to allow weight on the involved leg, functional exercises were added such as step-ups and heel raises (Brewster et al., 1983, Steadman, 1983). Steadman (1983) allowed patients to start running from 3 to 12 months after surgery depending on their strength. Brewster et al. (1983) allowed their patients to start jogging on a trampoline at 18 weeks and running outdoors at 28 weeks. After 30 weeks the patients started agility training such as running figure eights, backward running, and lateral running. Both Steadman (1983) and Brewster et al. (1983) allowed patients to return to full activity after one year with the use of a brace for another year. Curl et al. (1983) completed exercises in the water during the late healing stage of rehabilitation. Exercises included running, bicycle leg motion, flutter kicking, lateral shuffle and crossovers, and high stepping. Once the patient regained 70 to 80% of their strength they were allowed to complete exercises on dry land during the healing stage of rehabilitation. The final stage was the competition stage in which the patient returned to daily activities.

Turner and Blackburn (1985) published two separate rehabilitation protocols for an intraarticular and an extraarticular reconstruction. Patients who had intraarticular reconstructions were placed in a cast brace with extension locked at 45 degrees, and passive motion was allowed within the first week after surgery. Patients were not allowed to bear weight on the surgical leg for three months, then they started partial weight bearing on the leg with the brace locked at 10 degrees of extension. During the first six months after surgery exercises consisted of SLR in all directions with the brace on, at six months the cast brace is replaced with an athletic brace and exercises that

require a co-contraction between the hamstrings and quadriceps, such as leg presses and side step-ups, were started. After nine months a full extension program was started along with light squats, swimming, and walking up and down stairs. Patients were allowed to start running once they achieved 80% of their normal leg function. Patients who had extraarticular reconstructions were placed in a cast for six weeks with the leg in 45 degrees of extension. Range of motion was limited to 45 degrees of extension until 12 weeks after surgery, and flexion was gradually increased to 120 degrees by the same time period. After 12 weeks full extension was allowed as well as partial weight bearing and light exercises which increased in intensity by 18 weeks after surgery. Patients were allowed to participate in agility exercises after six months.

By 1988, some components of rehabilitation after an ACL reconstruction were beginning to change because of new research discoveries. Immobilization in long leg casts and weight bearing on crutches resulted in a 25% strength loss of the quadriceps, hamstrings and plantar flexor muscles (Gould, 1982 as cited by Silfverskiold, Steadman, Higgins, Hagerman, & Atkins, 1988). Huegal and Indelicato (1988) stated that the maximum amount of immobilization should be three weeks and only if a meniscal repair was completed along with the ACL reconstruction. Rehabilitation was starting to become more aggressive because of high-strength grafts and improved fixation techniques.

The first phase of rehabilitation included early restricted motion and either non-weight bearing or partial weight bearing. During the first post-operative week Mangine and Noyes (1988) allowed motion from 20 to 70 degrees or greater. Silfverskiold et al.

(1988) allowed 30 to 90 degrees of motion and Huegal and Indelicato (1988) allowed passive motions with no restrictions for up to six weeks. Mangine and Noyes (1988) allowed their patients to bear 25 to 50% of their body weight on the affected leg once pain and swelling had been controlled and full weight bearing by the fourth post-operative week. Silfverskiold et al. (1988) allowed their patients to bear weight as tolerated during the early rehabilitation phase, which lasted from the day after surgery to 8 weeks after the surgery. Huegel and Indelicato (1988) allowed weight bearing after 6 weeks if the patient had regained extension to at least 5 to 10 degrees. Silfverskiold et al. (1988) and Mangine and Noyes (1988) started their rehabilitation programs soon after surgery and would be called aggressive while Huegel and Indelicato (1988) started exercises after 6 weeks and were considered conservative. The early rehabilitation phase started from right after surgery to eighth weeks and consisted of active motion, hamstring-strengthening exercises, sport chord exercises and closed chain activities (Silfverskiold et al., 1988). The next period called intermediate rehabilitation, continued from the eight week to the twelfth week and increased repetitions and resistance to the same types of exercises as the early phase. Exercises that were added were single leg squats, forward and backward resistive walking, running in water, and stationary bicycle riding. Late rehabilitation took place from the twelfth week to the twentieth week after surgery. All of the same exercises were continued and movement with resistance from side-to-side was added. Patients were allowed to start agility drills and sport specific drills at 16 weeks with an athletic brace. Patients were able to resume full activity after 6 months of rehabilitation and those who wanted to play basketball, volleyball and football

returned after 8 to 10 months. Mangine and Noyes' (1988) rehabilitation protocol started in the first week after surgery. During this week the patient worked on active range of motion, weight bearing, quadriceps setting, SLRs, heel and toe raising, balance training, knee extension, and stretching to the hamstrings and calf muscles. During the second and third weeks, the same exercises were performed with greater repetitions, mini-squats were added and range of motion increased. During weeks 4 and 5 the patient was walking without crutches and had motion from 0 to 135 degrees. Isometric exercise on a Biodex machine, cable exercises in all planes with rubber tubing, lateral step-ups, knee extension and one-legged calf raises were added. Stationary bicycling, walking, water walking and stepping were added to the program, as all of the previous exercises were continued. Patients were allowed to start a running program and plyometrics after 20 weeks of rehabilitation. Huegel and Indelicato (1988) did not allow their patients to perform any active quadriceps activity before 6 weeks after surgery. Quadriceps sets, SLRs in 45 degrees of flexion, stationary bicycle, and isometric hamstring exercises were permitted after six weeks. After 16 weeks patients began to perform both isokinetic and isotonic quadriceps exercises up to 40 degrees of knee flexion, with high repetitions and low force. Patients should have had 65% of their normal strength back and be able to start jogging straight for short distances by 6 months post-operatively. Patients would perform balance activities, sport specific agility, sprinting, sidestepping, and backpedaling exercises before returning to sports activities. In order for patients to return to sports they must have achieved 85 to 90% of their quadriceps strength compared to their unaffected leg (Huegel & Indelicato, 1988).

Elkstrand (1989) used post-operative rehabilitation with early use of a continuous passive motion (CPM) machine, patellar mobilization and non-weight bearing walking. Between the second week and the fifth week, the goal of rehabilitation was to increase passive knee flexion with the help of patellar mobilization. At 5 weeks patients were placed in a hinged-type brace and range of motion was allowed from 20 to 90 degrees. The patient was started on partial weight-bearing walking, low resistance hamstring and quadriceps exercises, and stationary bicycling for functional coordination. Full range of motion was achieved at 9 weeks after surgery and the patient should have been walking without crutches by the third post-operative month. Jogging and isokinetic exercises were allowed after 4 or 5 months. If patients achieved full range of motion and 90% of their strength by 6 months, they were allowed to participate in sports.

From 1981 to 1987 Glasgow, Gabriel, Sapega, Glasgow and Torg (1993) conducted a study to determine the effects of early versus late return to vigorous cutting activity on patients who received an ACL reconstruction. All 186 patients received an ACL reconstruction with the medial third infrapatellar tendon, a bone block and superficial strip of quadriceps tendon. All patients completed the same post-operative rehabilitation program. Post-operatively patients were placed in a long leg cast at 30 to 40 degrees of knee flexion, and were non-weightbearing for 6 weeks. Range of motion began at 4 weeks from 0 to 90 degrees. Exercises for the quadriceps and hamstrings were begun at 6 weeks and consisted of isometric contractions. After 8 weeks patients were to begin to achieve full range of motion and start isotonic quadriceps and hamstring exercises. After this time it was believed by the authors that the biologic fixation of the

new graft was safe enough to allow the patients to progress aggressively as they tolerated, and the more motivated the patient was the sooner he or she could return to a previous level of activity. Group 1 was considered the early group and returned in less than 6 months, group 2, the late group, returned later than 6 months. The authors stated that since this study they have added components to their evolving rehabilitation program. They added immediate weight bearing in complete extension with a hinged locked brace, immediate passive range of motion, a concentration of closed kinetic chain exercises, and a completion of a sport-specific running and agility program. The authors concluded that an early return to activity, at a mean of 5 months, did not put patients at greater risk for reinjury, and early return did not result in less satisfaction by the patient. Shelborne and Nitz (1990) conducted a study on the effects of an accelerated rehabilitation protocol versus the effects of a conventional protocol. Two groups of patients who received the same ACL reconstruction followed two different rehabilitation programs. Group 1 consisted of 138 patients and they completed a rehabilitation protocol developed and used in 1984 and 1985 (Figure 5.1). After surgery the leg was splinted in slight flexion and the patient was allowed to bear partial weight with crutches during the first 6 weeks. Agility exercises were allowed after 7 or 8 months after the surgery. Patients were allowed to return to all activities with a brace after 9 months if Cybex strength results were greater than 80% of the normal leg, range of motion was close to normal, and a functional progression was completed. Group 2 completed a rehabilitation program used during 1987 and 1988, that was considered an accelerated program (Figure 5.2). The patients were not immobilized and continuous passive motion and weight bearing began

on the first day after surgery. Patients in this group usually returned to light sporting activities by 2 months, and full activity by 4 to 6 months after surgery. Shelborne and Nitz concluded, "an accelerated rehabilitation program, individually paced, with patients undergoing regular follow-up evaluations, offers advantages over conventional rehabilitation programs in terms of patient compliance and satisfaction and graft viability"(1990, p. 298).

Going into the 1990s physicians and clinicians were still differing in their rehabilitation protocols even though there were some aspects of rehabilitation that they did agree on. The majority believed that immobilization was not needed and that early protected motion was better to decrease the disuse effects, retarding capsular contracture, maintaining nutrition in articular cartilage, and allowing early controlled forces on healing collagen tissues (Lutz, Stuart & Sim, 1990). Shelborne, Wilckens, Mollabasy and DeCarlo (1991) conducted a study on arthrofibrosis after ACL reconstructions. They found that, "improved graft placement along with early motion have eliminated the need for immobilization which is considered one cause to post operative joint stiffness" (Shelborne et al., 1991, p. 332). They stated that using an aggressive rehabilitation protocol that emphasized full passive extension, muscle control, and functional exercise improved knee function (Shelborne et al., 1991). Mohtadi, Webster, and Fowler (1991) conducted a study in which one group was immobilized in a cast for 4 weeks with restricted motion for the next 6 weeks, a second group was put in a brace with restricted motion for 6 weeks, and a final group was non-weight bearing for 6 weeks. All three groups were to achieve full range of motion by 3 months post-operatively. Results

showed that all three groups suffered loss of motion at the end of rehabilitation. Lutz et al. (1990) divided their rehabilitation into five stages; the first stage was called the early-protected mobilization stage. Beginning on day one, the patient began protected motion from 30 to 90 degrees of knee flexion, being careful to avoid hypertension. The patient also completed isometric contractions of the hamstrings and quadriceps for at least 9 weeks. The second stage, the kinetic chain strength training stage, started the patient on open chain exercises for the hamstrings after 2 1/2 weeks, hip and ankle isotonic exercises at 4 1/2 weeks, and once the patient had achieved full weight bearing, closed chain exercise started at around 4 1/2 weeks. Toward the end of this stage open chain quadriceps exercises were allowed in a range from 30 to 90 degrees and power squats and leg pressed were allowed from 20 to 90 degrees. During stage three, the neuromuscular proprioceptive training stage, patients began exercises such as on the balance board, to improve dynamic joint control and also instill in the patient a greater level of confidence. Stage three began at 9 weeks post-operatively. After 4 to 5 months the patient must have pain-free range of motion, good dynamic joint control, strength in the quadriceps and hamstrings within 10% of the unaffected leg and an arthrometer measurement within 2 mm of the other leg in order to start stage four. The fourth stage was called the sport specific agility training stage, and allowed the patient to complete activities that are most like normal activities. After 6 months, the patient began to complete open chain quadriceps exercises to full extension. The final stage was the maintenance program, after the patient had returned to normal activities and sports, they continued closed chain exercises, open chain hamstring exercises, balance board exercises and aerobic

conditioning, to prevent a re-injury. Meystre (1992) had patients in a removable splint with the leg in 15 degrees of flexion for 5 weeks. On the second day active movement began from 10 to 40 degrees, increasing 25 degrees every 2 weeks until motion was 0 to 150 degrees by 12 weeks after surgery. He allowed isometric and isotonic exercises for the quadriceps and hamstrings early but no weight bearing for 7 weeks. After 10 weeks patients were allowed to begin proprioception exercises and riding the bicycle. At 12 weeks patients were allowed to start swimming and after 6 months they could start running. Patients were allowed to begin strenuous sports activities after 12 months. Jakob and Staubli (1992) created a functional rehabilitation program with specific goals to be met at the end of each phase, and specific directions for physical therapy.

Throughout the rest of the 1990s, rehabilitation became almost standard with few differences among physicians and clinicians. Immobilization had become obsolete and most patients were placed in a post-operative brace either locked at a certain range of motion or left free to allow unrestricted motion. In 1991, patients were allowed motion from 40 to 70 degrees (Meyers, 1991), 5 to 120 degrees (Rogan & Sepega, 1991), 20 to 90 degrees (Paulos, Cherf, Rosenberg, & Beck, 1991, Engle & Griesen, 1991), and 0 to 90 degrees (Barrett, Jimenez, & Thomas, 1991, Wittington & Carison, 1991). Most patients were allowed these restricted motions for a certain time period and allowed increased motion as time passed. These trends in the range of motion allowed by patients continued through 1992, allowing slightly lower ranges earlier in the rehabilitation protocol. Range of motion was allowed between 20 to 70 degrees (Mangine, Noyes, & DeMaio, 1992), 10 to 90 degrees (Agletti, Buzzi, D'Andria, & Zaccherotti, 1992), and

unlimited range of motion as the patient tolerated (Shelborne, Klootwyk, & DeCarlo, 1992). By 1993 most patients were placed in braces that were either locked in zero degrees of extension, or allowed free movement as they tolerated (Irrgang, 1993, Barber-Westin & Noyes, 1993). As the years passed, patients were placed in the continuous passive motion machine (CPM) immediately after surgery and the machine passively moved their knee to increase range of motion, afterwards they increased their active motion on their own. Physicians still reserved the right to restrict motion increases by time to protect healing tissues.

The decision whether to allow patients to place weight on the operated leg early has gradually changed from 1991 to the present time. In 1991, some patients were allowed to walk with the aid of crutches for a preliminary time and then gradually walk without the crutches. Meyers (1991) allowed patients to ambulate with the use of crutches after 1 week and walk without them as they tolerated. Rogan and Sapega (1991) recommended that patients walk with crutches for 5 weeks before putting all their weight on the operated leg. Engle and Gieson (1991) suggested that patients ambulate with partial weight bearing for 4 weeks then gradually increase to full weight bearing. Paulos et al. (1991) suggested the patient use 25% of their weight for 1 week and increase 25% a week until full weight bearing is reached. There were some that believed that the patient could bear weight as they tolerated early on with or without the use of crutches (Barrett et al, 1991, Wittington & Carlson, 1991). This difference of opinion on the safest amount of weight a patient could tolerate without disturbing the healing graft, continued until 1995 when there seemed to be a consensus toward allowing ambulation early as the

patient tolerated (MacDonald, Hedden, Pacin, & Huebert, 1995, Shelborne, Klotwyk, Wilckens, & DeCarlo, 1995). It was the decision of the physicians ultimately how they wanted to proceed with the issue of weight bearing, some still believed in starting their patients on a partial weight bearing regimen. Bynum, Barrack, and Alexander (1995) had patients bear partial weight right after surgery then let them gradually progress to full weight bearing. Howell and Taylor (1996) had patients toe-touch weight bearing for 3 weeks before allowing them to increase to full weight bearing. Clasby and Young (1997) suggested that patients should be allowed partial weight bearing for at least 6 weeks before attempting to bear full weight. There are still differences today between surgeons and their opinions on whether patients should be able to bear full weight after surgery, but decisions are made based on the patient and type of procedure used.

During the first phase of rehabilitation, the same general exercises to increase quadriceps activity and strengthen the hips were being used by virtually everyone. Quadriceps, hamstring setting and SLRs in all directions were standard exercises that were used right after surgery. Closed chain exercises were becoming more popular because they were thought to be safer for the healing ACL (Bynum et al., 1995). Exercises such as mini squats, calf raises, balance board exercises, and step-ups were initiated usually around the time that patients were allowed to start bearing weight. Open chain exercises for the hamstrings were started early on but open chain quadriceps exercises were restricted by range of motion or not started until later in the program. Paulos et al. (1991) suggested open chain hamstring exercises early during rehabilitation but quadriceps exercises were limited to 30 to 45 degrees of extension and not started

until 24 weeks after surgery. Agletti et al. (1992) allowed no knee extension exercises with heavy resistance in a 0 to 30-degree arc before 5 months after surgery. According to Mangine, et al. (1992), quadriceps extension exercises were limited to between 90 and 40 degrees and started at 4 weeks. According to Mangine and Noyes (1992), the exercises were limited from 90 to 30 at 6 weeks and the full range was allowed at 12 weeks. Irrgang (1993) suggested starting isotonic quadriceps exercises after 8 weeks, while starting closed chain exercises after the first week. Howell and Taylor (1996) allowed unrestricted closed and open chain exercises after 4 weeks. O'Neill (1996) allowed closed chain exercises after 6 weeks. There was still a difference of opinion as to when certain exercises should start and which should be avoided. Isokinetic exercises were being used in 1991 and 1992, but became less popular in the following years. Barrett et al. (1991) described using isokinetic exercises within 1 week after surgery but limited motion from 60 to 90 degrees of knee extension. Wittington and Carlson (1991) described using isokinetic exercises after 4 months of rehabilitation and Paulos et al. (1991) suggested using isokinetic exercise after 6 months with a 10-degree extension limitation. Mangine and Noyes (1992) suggested using isokinetic exercise after 6 weeks at high speeds such as 180 degrees per second and at 12 weeks, increase to higher speeds for endurance.

The next phase of rehabilitation usually consisted of exercise for agility and lateral movement. These phases usually occurred late in the rehabilitation program. Agility and sport-specific exercises started between 3 months (Engle & Gieson, 1991), and 8 months (Meyers, 1991). These exercises included lateral shuffles, jumping rope,

running figure eights, plyometrics, and cutting activities (Mangine & Noyes, 1992, Shelborne et al., 1995). These types of exercises were important in preparing athletes for their return to activity (Barber-Westin & Noyes, 1993). Running was another activity that was allowed later in the rehabilitation. There were differences of opinion as to when a patient should be allowed to run and on what type of surface. Shelborne et al. (1992) suggested that patients who had achieved 70% strength in their operated leg could begin running at 5 weeks. Howell and Taylor (1996) allowed patients to run after 8 weeks but only in a straight line. Others allowed patients to start running much later. Mangine and Noyes (1992) did not allow running until 8 months after surgery, and O'Neill (1996) suggested not allowing patients to run until after 3 months. Patients were returning to regular activity including sports as soon as 6 months (Barrett et al., 1991), and as late as 1 year after surgery (Engle & Gieson, 1991, Wittington & Carlson, 1991). This trend continued until patients were returning from 4 months (Howell & Taylor, 1996) to 6 months (O'Neill, 1996). Shelborne and Gray (1997) described patients returning as soon as 5 weeks after surgery. All cases were different and based on the type of patients, type of surgery performed, and whether there were complications or other structures which were repaired.

Currently, in an article by Wilk, Arrigo, Andrews, and Clancy (1999), a rehabilitation protocol is designed on functional rehabilitation, neuromuscular control and proprioception. They use an accelerated rehabilitation program for serious athletes and a less accelerated program for the recreational athlete. Their accelerated six-phase program (Figure 5.4) was developed to return the serious athlete to competition as fast and as

safely as possible while adhering to specific time frames based on the healing stages.

The program starts with establishing early knee extension and flexion and allowing early exercises such as quadriceps setting, SLRs and closed chain exercises beginning on the first day. Weight bearing is allowed as tolerated with crutches until 10 days then without as the patient tolerates. Knee extension exercises are allowed from the second day in a range of 90 to 40 degrees, and all exercises are gradually increased as time goes by. Agilities were started around 4 weeks, running between 10 and 16 weeks and return to sports is between 16 and 22 weeks.

In the time period from 1983 to the present, there has been an enormous amount of research on the post-operative rehabilitation after an ACL reconstruction. There have been changes in how to manage the ACL patient as safely as possible. Research has been used to change this management, and continues to evolve.

Chapter 6

Analysis of Changes in Rehabilitation

The procedures used for ACL reconstruction followed an evolutionary path from 1917 to the present day, as did the post-operative rehabilitation after surgery.

Rehabilitation started in 1917 from something very simple to be used after surgery to help patients recover and return to normal activities. There was not much attention paid to rehabilitation since the ACL reconstruction was still a highly skeptical procedure, and only used as a last resort. Research was just beginning and there was not much information available on the surgery or how after care should be handled. As the years passed, research improved and small changes started to occur. Most major changes in the post-operative rehabilitation occurred during the time period between 1983 and the present day. Prior to this time, small advances in technology, surgical techniques, and knowledge of function and physiology were causing slight changes in how patients were dealt with after surgery.

Rehabilitation began as a simple plan of immobilization with the patient on crutches and easy exercises after the cast was removed. The physician, as an extension of his services, carried out the rehabilitation of the patient. In 1916 the American Medical Association endorsed a specialty board for this type of medicine, called the Board of Physical Medicine and Rehabilitation (Gullickson & Licht, 1968). Rusk (1958) stated that "medical care cannot be considered complete until the patient with the residual physical disability has been trained to live and to work with what he has left" (p.1). During World War I general surgeons took care of orthopedic problems, but many started

to specialize in only orthopedic surgery (Aldes, 1967). Orthopedic surgery did not become a medical specialty until 1934, and it was not until 1947 that the first total rehabilitation program was instituted at New York's Bellevue Hospital. Because of this, research was limited or non-existent (Aldes, 1967). Palmer (1938) wrote an article on the injuries to the ligaments of the knee, their function, and mechanism of injury. He also described how to evaluate and diagnose the specific problems of the knee joint. Early research on the injuries to the knee was based on understanding the anatomy and mechanism of injury so that a correct plan of action could be used to treat many of the problems that occurred. The reason for most failures after ACL reconstruction was a combination of factors including graft replacement choices and graft placement (Naranja, et al., 1997). Because of lack of understanding and research, rehabilitation was conservative in nature for most knee injuries and early recognition and repair were not instituted until later, when patients still complained of instability. One of the problems with rehabilitation programs during the early years was that no one program was used by everyone; this was something that continued as the years passed on. Doctors had their own ideas of how to treat their patients.

Immobilization and Range of Motion

One element that stayed constant from 1917 to 1985 was that most patients were immobilized in either a long leg cast or brace immediately after surgery. There were differences, however, in what position the knee should be immobilized, in full extension or in a certain amount of flexion. Time periods for immobilization were different as well, ranging from 1 week to 3 months. Immobilization with the leg in a certain amount of

flexion continued up until the time that immobilization was deemed not necessary.

O'Donnell (1935) stated that since the ACL prevents knee extension, during treatment care must be taken not to allow strain on the healing ligament by extension. Paulos et al. (1981, p. 143) stated that "the forces created by extension which are present in the ACL are sufficient, in the initial healing period, to rupture weak and unorganized collagenous tissue". Many patients experienced a loss of motion after ACL reconstruction, which could affect the patient's gait and the ability to perform normal activities. Harner, Irrgang, Paul, Dearwater, and Fu (1992) completed a study to determine the cause of loss of motion after an ACL reconstruction. Loss of motion was defined as a loss of knee extension more than 10 degrees and knee flexion less than 125 degrees after 2 months. Patients were either placed in a brace locked at 30 to 45 degrees, 30 to 70 degrees or open from 0 to 90 degrees. Results showed that 18% of the patients experienced loss of motion in all groups. Harner et al. (1992) recommended that a goal for patients was to achieve full passive extension within 2 to 3 weeks after surgery. Anderson and Lipscomb (1989) looked at patients who were immobilized in flexion, in extension, and had continuous passive motion after an ACL reconstruction with a semitendinosus-gracilis graft. Their conclusions showed that there was no clear difference between immobilization in flexion or extension with regard to stability. Patients who were allowed continuous passive motion had less instances of undergoing manipulation. In 1970 a machine was introduced which created continuous passive motion (CPM) for joints. The benefits of motion were stated to be: decreased wound edema or hemoarthrosis, improved wound healing, decreased quadriceps inhibition, and decreased

post-operative pain (Silfverskoid et al., 1988). This machine did not become common until after research done by Salter in 1980 (Engstrom, Sperber, & Wredmark, 1995). According to Burks, Daniel, and Losse, (1984), Salter tested CPM on rabbit cadavers to examine the effects on anterior knee stability with three types of ACL reconstruction. Others began to follow in research on CPM to see if there were advantages or disadvantages to motion directly after ACL reconstruction. According to Burks et al. (1984), some advantages of CPM in post-operative care of ACL reconstructions are: decreased adhesions and increased range of motion, superior cartilage nutrition, improved orientation and strength of collagen fibers in the ACL graft, decreased post-operative pain and increased limb blood flow, and decreased thrombophlebitis. It was shown in a study completed by Bilko et al. (1986) that surgeons were no longer immobilizing their patients as long as previously. Their study results showed that in 1980 surgeons were immobilizing patients for up to 8 weeks, and in 1984 the majority of surgeons were immobilizing patients for no longer than 3 weeks. Noyes, Mangine, and Barber (1987) conducted a study in which they wanted to know if early range of motion after surgery would create more swelling in the knee than delayed motion. Two groups of subjects completed the same rehabilitation program except that the motion group started range of motion after two days from 0 to 90 degrees and the delayed group started motion after 7 days with restrictions in active and passive range of motion. The results showed that early motion did not create more effusion or soft-tissue swelling. Another perceived effect of CPM was the reduction of pain after surgery. A study by McCarthy, Yates, Anderson, and Yates-McCarthy (1993) investigated the question as to whether use of

CPM directly after surgery would reduce the post-operative pain. Thirty patients were randomly placed into two groups, CPM and non-CPM. Pain was measured by the number of times a patient gave themselves a dose of pain medication, and rated their pain on a perceived pain scale. Results showed that the group using the CPM had a significantly less amount of pain than the group who did not use the CPM. This was determined by the number of times the patients gave themselves a dose of medication.

The studies completed on the benefits for the use of the CPM machine increased the use of this product, but it is important to understand that motion either completed actively or passively directly after ACL reconstruction, improved the rehabilitation process. In a study by Rosen, Jackson and Atwell, (1992) it was determined that CPM produced by the machine and active and passive motion performed by the patient had no significant differences and showed identical results. Even though most patients who receive an ACL reconstruction are not immobilized any more, there are still differences between physicians regarding the amount of early motion that is allowed and safe. Most patients now try to achieve full extension early and increase flexion gradually.

In conclusion, immobilization changed from up to 3 months, to only 3 weeks because research indicated that immobilization created loss of motion. This loss of motion created abnormal gait and an inability for patients to perform daily activities, as well as more instances of patients having to undergo manipulation under anesthesia. Therefore, programs focused on early passive extension by 3 weeks. Research also indicated that ROM was considered important because it decreased wound edema,

adhesions, thrombophlebitis and pain. Range of motion also changed because it was found that it increased wound healing, cartilage nutrition, and blood flow.

Time to Ambulation

The decision as to when to allow patients to bear full weight on the affected leg after an ACL reconstruction is one that is still based on the physician, patient, and type of procedure used during surgery. As time has passed patients have been on crutches, and not allowed to bear weight from 4 months to 6 weeks. As the idea of creating a more aggressive rehabilitation protocol has evolved, patients are ambulating without crutches earlier to practice correct “heel to toe” gait patterns. Once full knee extension is achieved, now within the first week, most patients are starting to begin full weight bearing activities. Most patients are allowed to bear weight with the use of crutches right after surgery. Directly after surgery, pain and swelling are at their greatest and because of these factors, the patient is at risk of the having muscles of the knee being unable to contract and keep the patient from falling. As pain and swelling are controlled and quadriceps firing is initiated, ambulating becomes safer. Another factor in early ambulation is that most ACL reconstruction surgeries are performed on an outpatient basis. Because of health care costs, patients do not stay overnight in the hospital unless they have complications. Before a patient leaves the hospital, they are trained in crutch-use and encouraged to use the crutches to get around.

Changes in the amount of time a patient was able to ambulate without the use of crutches occurred because physicians believed that gait training did not cause excessive

stress on the healing graft. A patient's ability to display correct gait patterns was important to prevent loss of motion, and weakness in the quadriceps muscle.

Exercises

Exercises after an ACL reconstruction consisted of quadriceps setting and SLRs for most patients until a more scientific approach to exercise was created by DeLorme in the 1940s. According to Prentice (1994), DeLorme developed an isotonic exercise program that was based on three sets of 10 repetitions. First the patient determined their 10 RM (the highest amount of weight that can be lifted 10 times), and then the first set of 10 repetitions was lifted at half of the 10 RM. Following this, a second set is lifted at $\frac{3}{4}$ of the 10RM, with the final set lifting the full 10RM. The patient increased their 10RM every week therefore increasing strength. He called this technique progressive resistive exercise (PRE). Other programs followed DeLorme such as the Oxford technique and the daily adjustable progressive resistive exercise (DAPRE) technique (Prentice, 1994). ACL patients were being instructed in these types of programs to increase their strength after surgery. It was found that strength imbalances were present between the involved and uninvolved legs of ACL patients and that patients felt their operated leg was less stable. Brenner and Klein (1962) recommended that when an imbalance was present after knee surgery, the imbalance should be eliminated with use of PREs. After 1955, exercise started to emphasize the hamstrings and their importance in ACL reconstruction because there was no strain on the ACL graft while they were being performed. Quadriceps exercises were performed in the last 10 to 15 degrees to strengthen the vastus medialis, which was thought to be the key to knee stability (Klein & Allman, 1969).

As exercises became more and more necessary for total recovery and return to normal activities, the exercises and their effect on the healing graft became the subject of research. Sachs, Daniel, Stone, and Garfein (1989) found the most prevalent complications for patients who had ACL reconstruction between 1982 and 1986, were quadriceps weakness, flexion contracture, and patellofemoral pain. Research started to focus on the biomechanics of the knee extensor mechanism to find the safest exercises for the healing ACL. By the early 1990s, researchers were placing greater importance on closed kinetic chain exercise (CKC) during rehabilitation because they were said to be safer than open kinetic chain exercises (OKC). Knee extension exercises between 60 and 90 degrees were encouraged but patients complained of patellofemoral pain with extension between 0 and 30 degrees (Palmiter, An, Scott, & Chao, 1991). Palmiter et al. stated that CKC exercises decrease the strain on the ACL because there is a co-contraction between the quadriceps and the hamstrings, thus each force created is canceled out. Activities such as walking, running, jumping, and climbing are all exercises that utilize the kinetic chain, so rehabilitation should mimic these activities. Irrgang (1993) stated that when designing a rehabilitation program, one must consider the effects that exercise and activity will have on tibial translation as well as on the strain and load of the original or substitute ACL. The ACL protects the knee by preventing anterior tibial translation. After ACL reconstruction the new graft is at its strongest but by 6 weeks it shows signs of avascular necrosis and starts revascularizing between 8 and 10 weeks. Exercises should be used knowing these time periods. Open chain activities increase anterior translation therefore increasing strain on the ACL.

Because of this claim that OKC exercises should be replaced with CKC exercises, research focused on the strain imposed on the knee. Yack, Collins, and Whieldon (1993) tested the amount of anterior tibial displacement occurring in ACL-deficient knees, during a parallel squat (CKC) exercise and a seated knee extension (OKC) exercise. Results showed that OKC exercise created more anterior tibial displacement than CKC exercise in the ACL-deficient knee. Lysholm and Messner (1995) tested a variety of exercises to predict which would be recommended for rehabilitation after an ACL reconstruction. They found that isokinetic exercises at 30 degrees per second increase anterior tibial translation, as well as isometric quadriceps and hamstrings exercises on an isokinetic machine at 20 degrees. As resistance on a stationary bike increases so does the anterior tibial translation. The exercises that they recommended as the safest for rehabilitation were weight bearing exercises, isometric quadriceps exercises without resistance, isometric hamstring exercises in 45 degrees of knee flexion, and stationary bicycling at low resistance. Beynnon, et al. (1995) stated that "an optimal rehabilitation program should restore normal range of joint motion, rapidly return strength of the leg musculature to the preinjury level, and yet not produce excessive strain along the graft so that it can heal without permanent elongation of injury" (p. 24). They studied the effects of different exercises on subjects with normal ACLs. Their study identified that exercises which created low or no strain on the ACL included isometric quadriceps exercises at 60 and 90 degrees of knee flexion, isometric hamstring exercises at 15, 30, 60, and 90 degrees of knee flexion, CKC exercises at 30, 60, and 90 degrees of knee flexion, and

active flexion and extension motion without weight between 35 and 90 degrees of knee flexion.

Although there have been many studies done to suggest that CKC exercises are better than OKC exercises, a paper written by Fitzgerald (1997), challenges these claims. Fitzgerald states that the arguments in favor of CKC exercises over OKC are that they are safer, create less strain on the ACL graft and less patellofemoral pain, are more functional, and are equally effective in improving the quadriceps femoris. He argued that the studies completed did not indicate that CKC exercises are safer because they were performed on subjects that either had no ACL or had a normal ACL. He stated that in theory both types of exercises could be performed within certain ranges of motion that will not strain the ACL. He also stated that research needs to be done on the effects of exercises on a healing graft. Fleming, Beynnon, and Perula (as cited by Fitzgerald, 1997) stated that if an ACL graft is properly placed during surgery then one could assume that the strain on the graft might not be different between CKC and OKC exercises. Another argument in favor of CKC exercises is that they are more functional because they are weight bearing exercises. Fitzgerald argued that evidence is lacking in this statement, and that exercises such as running and walking also utilize the OKC so both types of exercises should be used in rehabilitation. The last argument for CKC exercises was that they were equally effective in improving the quadriceps femoris muscle strength. Snyder-Mackler (as cited by Fitzgerald, 1997) found that CKC exercises alone may not be enough to correct strength deficits after ACL reconstruction. Fitzgerald stated that the best alternative is use of both OKC and CKC because if used in restricted range of

motion, OKC exercises have less chance of the patient substituting other muscles for the muscle that is intended to be worked on. Fitzgerald believed that more research is needed and that therapists should not use one or the other in rehabilitation, but use both in ranges that are not stressing the healing graft.

Exercises changed from not having a very great importance in rehabilitation to becoming one of the most important factors, because patients were complaining that their knees felt weak and unstable. Researchers found that strengthening of the thigh would improve the long-term effects of ACL reconstruction. Open kinetic chain exercises were replaced by closed kinetic exercises because research suggested that these exercises were safer, more functional, and caused less pain to the patient.

Time to Return to Activities

The last factor in ACL rehabilitation to be considered is the amount of time it took for patients to return to normal activities including sports. Early on, patients were said to return to jobs in 4 to 6 months, after an ACL repair, only to need a reconstruction later. As research indicated, patients were receiving reconstruction earlier than previously, therefore completing rehabilitation and returning to normal activities about a year after receiving the surgery. Friedman et al. (1985) stated that the indications for an ACL reconstruction were: functional disability in patients who are unwilling to alter their athletic lifestyles, patients who are having symptoms with activities of daily living, and failure of the knee after 6 months of rehabilitation. The idea of an aggressive rehabilitation program was suggested by Shelborne and Nitz (1990). An aggressive rehabilitation program utilizes all of the factors that have changed over the years,

immobilization, range of motion, full ambulation, exercises and created an earlier return to activities. A patient who underwent an aggressive rehabilitation program returned to normal activities in 6 to 8 months during 1990. According to DeMaio, Noyes, and Mangine (1992), the indications for an aggressive rehabilitation program after an ACL reconstruction are: a high strength graft, preferably bone-patellar tendon-bone, isometric graft placement, control of post-operative inflammation, serial post-operative evaluation of anterior/posterior displacements, patient compliance and serial follow-up by surgeon and therapist. Reasons for earlier return to activities include no immobilization after surgery and early-restricted range of motion. Once a patient has achieved full range of motion and has begun to ambulate, they are ready to start exercises that will improve their strength balance and proprioception. The sooner all of this happens, the sooner the patient can return to daily activities and sports participation. This does not mean that all patients who have an ACL reconstruction will return to normal activities in 6 months or less, every patient is different and the physician plans accordingly. Stanish and Lai (1993) stated that rehabilitation programs must be modified for each person based on: their age and sex, the time from the initial injury, any previous surgery which may have compromised range of motion, any associated pathology particularly meniscal damage and osteoarthritis, and the patients motivation and attitude.

The time to return to normal activate changed because patients were no longer being immobilized in long leg casts for prolonged periods of time and early range of motion was initiated.

The changes in immobilization, range of motion, time to ambulate, exercises and return to activities all lead to an accelerated rehabilitation program. When an elite or collegiate athlete sustains an ACL rupture and requires an ACL reconstruction, there are enormous stresses for that athlete. An accelerated rehabilitation program after an ACL reconstruction can benefit athletes by returning them to competition more quickly. Conservative rehabilitation programs for an ACL reconstruction take more time and because of this, can cause more depression and stress on the athlete. With an accelerated program the athlete can feel secure that he or she will return to competition without any possibilities of loss of scholarship. Athletic trainers, who treat athletes, are under extreme pressure by coaches and athletic department administrators to get injured athletes back to competition as soon as possible. An accelerated program aids them in this effort without compromising their safety. In the private sector, someone who requires ACL reconstruction may lose valuable income because of being off work for some period of time. A lay person who is injured and off work because of an ACL reconstruction will return to his or her job quicker than that using a conservative program, thereby not losing as much of his or her pay. Insurance companies pay less money in re-imbursment of medical bills if the patient returns more quickly. The health care system has changed in the last 25 years, from insurance companies paying more benefits, to Health Maintenance Organizations (HMO) becoming more commonplace. A patient who is receiving therapy for an ACL reconstruction usually is limited by their insurance company to a certain number of visits that they will pay, causing the patient to be responsible for any visits after the limited number. Because of this limited number of visits that insurance

companies pay, doctors and therapists are forced to raise fees for each visit. Accelerated rehabilitation has helped to limit this cost to patients. There are some consequences to accelerated rehabilitation. If a patient is pushed too hard too soon, there is a chance of complications that will lead to prolonged disability and missed work or competition. An accelerated rehabilitation program may not be right for every patient, and each patient should be evaluated to decide if this type of program would be the safest and most effective.

Since 1917, the ACL reconstruction and the rehabilitation after the procedure, have evolved into common procedures. Because of research and technological advances these procedures have changed with time. Even though advances have been made, there is still room for improvement in the surgical procedure and the rehabilitation process. Now that researchers understand more about the ACL and its healing properties, the future can only make these procedures improve.

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Figure 1.1 Inside Anatomy of the Knee. Printed with permission: The Center for Orthopedics and Sports Medicine. <http://www.arthroscopy.com>

Figure 1.2 Anatomy of the Knee, anterior view. Printed with permission: The Center for Orthopedics and Sports Medicine. <http://www.arthroscopy.com>

Rehabilitation protocol, 1984 through 1985	
Time after reconstruction	Rehabilitation program
Day 1	Leg splinted at 10° flexion, continuous passive motion (CPM) begun
1-3 days	Ab/adduction straight leg raises (SLR), extension SLR, passive range of motion (ROM) 0°-90°, znuetel sets, ambulation (nonweight-bearing), crutches
4-6 days	Discharge from hospital, CPM and exercises continued at home, rigid knee immobilizer (set at 10°) used except during passive knee ROM exercises, hamstring curls, ab/adduction and extension SLR, toe touch weight-bearing
2 weeks	Quadriceps exercises, active ROM 60° to 90°, gradual light resistance. Note: Patients should have attained passive ROM of 0°-90° assisted by CPM or the well leg. Continue Dohi splint when up. May discontinue for sleep.
4 weeks	Passive ROM 0° to 100°, weightbearing as tolerated, wear IKO (functional knee brace) 16° stops, full time when walking
5-10 weeks	Full weightbearing as tolerated, active ROM 0 to 110 degrees, passive stretching to increase ROM, SLR with increased weights, eccentric knee extensions, short arc knee extension 90° to 45°, hamstring curls, swimming, stationary bicycling when patient able to walk without crutches. Note: If patient has not attained full extension, regimen includes lying prone with 1 pound weight on ankle
12-14 weeks	ROM 0° to 120°, full weightbearing, previously described exercises continued, knee bends, step-ups (well leg first), step-down, operated leg first, calf raises
4 months	ROM 0° to 130° (goal), brace discontinued for activities of daily living (ADL) if patient's quadriceps tone is good, exercises increased in intensity with higher weights and more sets and repeats, fast speed isokinetics
5 months	Jumping rope
6 months	Cybex at 180 and 240 deg/sec with a 20° block, KT-1000, lateral shuffles, walking up to 2 miles per day, short arc knee extensions to full knee extensions, squats, use of brace for activities other than ADL
7-8 months	Cybex, KT-1000, walking, progressive running and jogging; weight lifting continued to strengthen quadriceps, hamstrings, and calf muscles; jogging followed by progressive running program, including backward running and hill running; agility drills including large (gentle) figure of eights; lateral shuffles; slow and fast speed isokinetic strengthening exercises
9-12 months	Return to normal activity levels if strength greater than 80% of the nonoperated knee, full ROM, no pain or swelling, successful completion of functional progression

Figure 5.1 Printed with permission from:
 Shelborne & Nitz (1990). Accelerated rehabilitation after ACL
 reconstruction, *The American Journal of Sports Medicine*, 18 (3), 293.

Time after reconstruction	Rehabilitation program
Day 1	Continuous passive motion (CPM), rigid knee immobilizer in full extension for walking, weightbearing as tolerated without crutches
2-3 days	CPM, passive range of motion (ROM) 0° to 90° (emphasis on full extension), weightbearing as tolerated without crutches
2-4 days	Discharge from hospital; CPM at home. <i>Note:</i> Prerequisite to discharge is 1) satisfactory pain management, 2) full extension symmetrical to nonoperated knee, 3) able to do SLR for leg control, 4) full weightbearing with or without crutches
7-10 days	ROM terminal extension, prone hangs (2 pounds) if patient has not achieved full extension, towel extensions, wall slides, heel slides, active-assisted flexion, strengthening—knee bends, step-ups, calf raises; weightbearing—partial to full weightbearing; gradual elimination of required use of knee immobilizer
2-3 weeks	ROM (0° to 110°), unilateral knee bends, step-ups, calf raises, StairMaster 4000, weight room activities: leg press, quarter squats and calf raises in the squat rack, stationary bicycling, swimming, custom-made functional knee brace with no preset limits (to be used at all times out of the home for the next 4 weeks)
5-6 weeks	ROM (0° to 130°), isokinetic evaluation with 20° block at 180 and 240 deg/sec. When strength is 70% or greater than the opposite unoperated knee, the patient can begin lateral shuffles, cariocas, light jogging, jumping rope, agility drills, weight room activities, stationary bicycling, and swimming. <i>Note:</i> Functional brace discontinued (except for sports activities) when muscle tone and strength are sufficient.
10 weeks	Full ROM, isokinetic evaluation at 60, 180, and 240 deg/sec, KT-1000, increased agility workouts, sport-specific activities
15 weeks	Isokinetic evaluation, KT 1000, increased agility workouts
4-6 months	Return to full sports participation (if patient has met criteria of full ROM, no effusion, good knee stability, and has completed the running program)

Figure 5.2 Printed with permission from: Shelborne & Nitz (1990). Accelerated rehabilitation after ACL reconstruction, The American Journal of Sports Medicine, 18 (3), 294.

Table 3. Accelerated Rehabilitation for ACL PTG* Reconstruction (Isolated)

I. 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
Weightbearing:	As tolerated with or without crutches
Exercises:	Ankle pumps Passive knee extension to zero Passive knee flexion to tolerance Straight-leg raises Quadriceps setting Hip abduction and adduction raises Closed kinetic chain exercises: minisquats, lunges, step-ups
Muscle stimulation:	Electrical muscle stimulation to quadriceps during voluntary quadriceps exercises (4 to 6 h/d)
Cryotherapy/elevation:	Apply ice 20 min 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
II. Immediate Postoperative Phase (Day 1 through 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 1:	
Brace:	EZ Wrap Brace (Professional Products, DeFuniak Springs, FL) or immobilizer applied to knee, locked in full knee extension during ambulation
Weightbearing:	2 crutches, weightbearing as tolerated
Exercises:	Ankle pumps Overpressure into full, passive knee extension Active and passive knee flexion (90° by day 5) Straight-leg raises Quadriceps isometric setting Hip abduction and adduction Hamstring stretches Closed kinetic chain exercises: minisquats, weight shifts
Continuous passive motion:	As needed, 0° to 45° to 50° (as tolerated and as directed by physician)
Muscle stimulation:	Use muscle stimulator during active muscle exercises (4 to 6 h/d)
Ice and elevation:	Ice 20 min of every hour; elevate leg with knee in full extension
Postoperative Days 2 to 3:	
Brace:	EZ wrap brace and immobilizer locked at zero
Weightbearing:	2 crutches as tolerated
Range of motion:	Remove brace, perform range-of-motion exercises 4 to 6 times a day
Exercises:	Multiangle isometrics at 90° and 60° (knee extension) Knee extension 90° to 40° Patellar mobilization Overpressure into extension Ankle pumps Straight-leg raises (3 directions) Minisquats and weight shifts Standing hamstring curls Quadriceps isometric setting
Muscle stimulation:	to quadriceps during exercises (8 h/d)
Continuous passive motion:	0° to 90° as needed

Table 3. Continued

Ice and elevation:	Ice 20 min of every hour and elevate leg with knee in full extension
Postoperative Days 4 to 7:	
Brace:	EZ Wrap/immobilizer
Weightbearing:	2 crutches, weightbearing as tolerated
Range of motion:	Remove brace, perform range-of-motion exercises 4 to 8 times per day; knee flexion 90° by day 5, approximately 100° by day 7
Exercises:	Continue all exercises as listed in postoperative days 2 and 3 and progress proprioception and balance drills
Muscle stimulation:	Apply to quadriceps during active exercises
Continuous passive motion:	0° to 90° as needed
Ice and elevation:	Ice 20 min of every hour and elevate leg with knee in full extension
III. Early Rehabilitation Phase (Week 2 through Week 6)	
Goals:	Maintain full passive knee extension Gradually increase knee flexion Diminish swelling and pain Muscle training Restore proprioception Patellar mobility
Criteria to progress to phase III:	Quadriceps control (ability to perform good quadriceps set and straight-leg raise) Full passive knee extension Passive range of motion from 9° to 90° Good patellar mobility Minimal joint effusion Independent ambulation
Week 2:	
Brace:	Discontinue brace or immobilizer at 2 to 3 wk
Weightbearing:	As tolerated (goal is to discontinue crutches at 2 wk)
Range of motion:	Self-ROM stretching (4 to 8 times a day), emphasis on maintaining full, passive range of motion
KT-2000 test:	6.75-kg anterior-posterior test only
Exercises:	Muscle stimulation to quadriceps during 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 Wall-leg exercises Progressive resistance exercise program (begin with 1 kg, increase by .45 kg per wk)
Week 3:	
Brace:	Discontinue
Range of motion:	Continue range-of-motion stretching and overpressure into extension
Exercises:	Continue all exercises as in wk 2 Passive range-of-motion exercises from 0° to 115° Bicycle for range-of-motion progression Pool-walking program (if incision is closed) Eccentric quadriceps program Lateral lunges Lateral step-ups

Figure 5.3 Printed with permission from: Wilk et al. (1999). Rehabilitation after ACL reconstruction in the female athlete. *Journal of Athletic Training*, 34, 181-182.

Table 1. Continued

Front step-ups
Lateral step-overs (cones)
Step-stopper machine
Progress proprioception and neuromuscular control drills
Intermediate Phase (Week 4 through Week 10)
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
Criteria to enter phase IV:
Active range of motion from 0° to 115°
Quadriceps strength 80% of contralateral side (isometric test at 60° of knee flexion)
Unchanged KT bilateral values
Minimal to no joint effusion
No joint line or patellofemoral pain
Brace: no immobilizer or brace; may use knee sleeve (Bauerfeind Compfix brace, Bauerfeind USA, Kennesaw, GA)
Range of motion: self-ROM 4 to 5 times per day (using the other leg to provide ROM)
KT-2000 Testing
Week 4: 9-kg test
Weeks 8 through 10: 9- and 13.5-kg tests
Week 10:
Progress isometric strengthening program
Leg press
Leg extension from 90° to 45°
Seated curls
Leg abduction and adduction
Leg flexion and extension
Lateral step-overs
Lateral lunges
Lateral step-ups
Lateral step-downs
Heel squats
Frontal squats
Self raises
Knee stability system (balance, squats, etc.)
Proprioception drills
Step-stopper machine
Running program (backward running, hip and leg exercises)
Week 6:
Continue all exercises
Running (forward) and agility drills
Balance on tilt boards
Throws to balance board throws
KT-2000 test (9- and 13.5-kg tests)
Week 8:
Continue all exercises listed in weeks 4 through 6
Isometric leg press
Balance training
Agility exercises (50° to 40°) (12U to 240°)
Running program
Step for endurance
Step-stopper machine for endurance
KT-2000 test 9- and 13.5-kg test
Week 10:
KT-2000 test 9- and 13.5-kg and manual maximum test
Isometric test: Rest concentric knee extension and flexion at 180° and 300°

Table 3. Continued

Exercises: Continue all exercises listed in wks 6, 8, and 10
Plyometric training drills
Continue stretching drills
V. Advanced Activity Phase (Week 10 through Week 16)
Goals: Normalize lower extremity strength
Enhance muscular power and endurance
Improve neuromuscular control
Perform selected sport-specific drills
Criteria to enter phase V:
Active range of motion from 0° to 125° or greater
Quadriceps strength 70% of contralateral side, knee
flexor:extensor ratio of 70% to 75%
No change in KT values (comparable with contralateral side, within 2 mm)
No pain or effusion
Satisfactory clinical examination
Satisfactory isokinetic test (values for females at 180 degrees)
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 ²⁰)
80 points or better
Continue all exercises listed in wks 10-12
VI. Return-to-Activity Phase (Week 16 through Week 22)
Goals: Gradual return to full unrestricted sports
Achieve maximal strength and endurance
Normalize neuromuscular control
Progress skill training
Criteria to enter phase VI:
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 examination
Subjective knee scoring (modified Noyes System: 80 points or better)
Tests: KT-2000, isokinetic, and functional tests before return
Exercises: Continue strengthening program
Continue neuromuscular control drills
Continue plyometric 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

* PTG = patellar tendon graft.

restoring full passive knee extension to decrease postoperative complications such as arthrofibrosis.^{20,31} Additionally, muscle-training exercises are performed to prevent muscular atrophy.

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Dear Ms. Donaldson:

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