ORIGINAL RESEARCH

REHABILITATION OF PATIENTS FOLLOWING AUTOGENIC BONE-PATELLAR TENDON-BONE ACL RECONSTRUCTION: A 20-YEAR PERSPECTIVE

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ABSTRACT

Rehabilitation of patients following anterior cruciate ligament (ACL) reconstruction has undergone remarkable improvements over the past two decades. During this time, ACL research has been at the forefront of many orthopaedic and sports physical therapy clinics. With over 20 years of ACL rehabilitation experience (senior author) and prior collaboration with accelerated ACL rehabilitation pioneer K. Donald Shelbourne, the authors wish to present a unique perspective on the evolution of ACL rehabilitation.

Prior to the classic article by Paulos et al in 1981,[1] literature on ACL rehabilitation was quite sparse. The basis for ACL rehabilitation at this time was founded in basic science studies conducted with animal models. In an effort to protect the graft, emphasis was placed on immobilization, extension limitation, restricted weight bearing, and delayed return to activity. Despite achieving good ligamentous stability, patients often experienced a spectrum of complications.

In 1990, Shelbourne and Nitz[2] proposed an accelerated rehabilitation protocol following ACL reconstruction based on clinical experience. Their program emphasized delayed surgery, earlier range of motion and weight bearing, and full extension. As a result, patients experienced better clinical outcomes while maintaining knee stability.

The rehabilitation program presented in this paper is still largely based on the principles of the accelerated protocol. As evidence-based practice and the call for prospective, randomized clinical research continues, the continued progress in treating patients with this injury will be enhanced. Furthermore, clinicians are urged not to lose sight of the clinical reasoning that helped evolve the ACL rehabilitation process where it is today.

Key words: anterior cruciate ligament, knee, postoperative, evidence-based practice.

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INTRODUCTION

Rehabilitation of patients following anterior cruciate ligament (ACL) reconstruction has undergone remarkable improvements over the past two decades. In 1983, one author reported on "The Anterior Cruciate Ligament Problem," indicating no ideal treatment for a patient with ACL disruption existed.[3] Initial surgical treatment of ACL injuries resulted in a high incidence of complications, which led many authors to favor nonoperative treatment and conservative rehabilitation.[3] As surgical techniques improved and surgical outcomes became more predictable, postoperative rehabilitation became the key variable in determining successful outcomes.

Prior to the classic article by Paulos et al,[1] literature regarding ACL rehabilitation was scarce. Initial reports of rehabilitation of patients following ACL reconstruction consisted of a few general paragraphs at the end of an article regarding surgical procedures. From 1980 to 1985, ACL literature increased dramatically as the period produced more articles than the previous 80 years.[4] Since this time, ACL research has been at the forefront of many orthopaedic and sports physical therapy clinics.

With over 20 years of ACL rehabilitation experience (senior author) and prior collaboration with accelerated ACL rehabilitation pioneer, K. D. Shelbourne MD, the authors wish to present a unique perspective on the evolution of ACL rehabilitation. The term accelerated rehabilitation will be used for the context of this paper to refer to the concept of a rehabilitation progression designed to allow early, yet safe return to activities following ACL reconstruction. The term traditional rehabilitaion will be used to describe the more conservative, time-based, protocols that were commonly used in the past. This commentary will provide a brief history of the basic science models that led to the traditional rehabilitation protocols, highlight rehabilitation models proposed by Paulos et al[1] and Shelbourne and Nitz,[2] provide evidence for the principles behind the accelerated rehabilitation program following ACL reconstruction, and re-emphasize key points to successful rehabilitation outcomes following ACL reconstruction. Although the impact of surgical technique and graft selection on the rehabilitation process is important, such topics are beyond the scope of this paper.

BASIC SCIENCE MODELS

During the 1970's, basic science studies conducted with animal models provided the framework for the traditional rehabilitation model. This data was extrapolated and applied to humans. Application of animal studies should be done with caution due to the differences between the species. Many authors openly stated this limited applicability to clinical human cases.[1,5,6] However, clinicians acted on the best available evidence at the time.

Great uncertainty existed as to the role of the ACL in knee joint stability and the long-term effects of knee instability.[7] A classic study by Marshall and Olsson[8] transected the ACL in 10 dogs and two dogs were used as a control group. The dogs were followed for up to 23 months. Macroscopic, histological, and microroentgenographic examinations revealed osteophytes progressively increasing in size for up to one year as well as proliferative and degenerative changes in the articular tissues. A close relationship existed between instability evaluated by an anterior drawer test and articular changes. The authors concluded that early stabilization was indicated in cases of ACL rupture. A biomechanical study by Butler et al[9] sought to determine the importance of knee ligaments in resisting joint translation. They used 14 human cadaver knees secured to a load cell and moving actuator to measure the restraining forces against the anterior and posterior drawer tests. Ligaments were sectioned individually and the test repeated to determine the contribution to restraint. Test result indicated that the ACL provided up to 86% of restraint against anterior translation in the knee. As the function of the ACL and the need for stabilization became clearer, the number and type of surgical procedures increased.[4]

Following ACL disruption and reconstruction or repair, immobilization for an extended period of time was the standard form of treatment. Noyes and colleagues[5,10] reported the functional properties of ligaments in monkeys. Wild primates were immobilized for eight weeks in total body plaster prior to undergoing mechanical testing in tension to failure under high strain-rate conditions. The results of testing on 100 knee specimens showed a significant decrease in ligament strength and stiffness following 8-weeks of immobilization. Two subgroups of monkeys underwent 5 and 12 month reconditioning periods prior to testing. Results showed incomplete recovery of ligament properties 5 months after resumed activity and strength properties required up to 12 months to return to normal. As a result, they suggested delayed return to activity for an extended period of time following immobility, delayed return to strenuous activity for 6 to 12 months, and prescribed protective measures during rehabilitation. The application to humans suggested an extended delay for return to activity rather than shortening the length of immobilization.

The vascular anatomy and healing process of the ACL were described in dogs. Arnoczky et al[11] utilized microangiography, histology, and tissue-clearing techniques to analyze the normal vascular anatomy in eight dogs. They reported that the central portion of a normal canine ACL had decreased vascularity. Eight weeks following complete ACL transaction, spontaneous healing had not occurred in one animal. Alm et al[12] studied the revascularization process following ACL reconstruction in 29 dogs. Through microangiography and histological study, they found that the original vascularization of the distal and middle portionss of the patellar tendon graft were preserved. The proximal and middle parts of the graft where the suture was attached were initially devoid of functioning vessels and had revascularized by 2 months. The structure of the graft resembled a normal ligament at 4 to 5 months.

Clancy and coworkers[13] studied the vascularity of the patellar tendon graft in monkeys at 2, 3, 6, 9, and 12 months following ACL reconstruction. Microangiographic and histologic examinations were performed on one animal at each of the follow-up periods. They found that patellar tendon grafts in monkeys were revascularized after 8 weeks and resembled a normal ligament at 9 months and 12 months. Arnoczky et al[14] studied the revascularization pattern of patellar tendon grafts in dogs at 2, 4, 6, 8, 10, 16, 20, 26, and 52 weeks post-operatively. Four animals underwent histological and tissue-clearing techniques at each of the follow-up periods. The authors described the graft undergoing phases of ischemic necrosis, revascularization, proliferation, and remodeling. The transplanted graft had intrinsic vessels by 8 weeks, was completely vascularized by 20 weeks, and had the histological appearance of a normal ligament at one year. Amiel et al[15] studied the morphology of patellar tendon grafts in rabbits at 2, 3, 4, 6, and 30 weeks following ACL reconstruction. Histological and biochemical examination were performed on five animals at each of the follow-up periods. The grafts demonstrated a gradual assumption of the microscopic properties of the normal ACL. By 30 weeks postoperatively, collagen concentrations of the graft were the same as the normal ACL and cell morphology appeared ligamentous. The authors referred to this gradual process as "ligamentization." The common theme during this time period was that vascularization of a transplanted graft required 8 weeks and ligamentization required up to one year.

Rougraff et al[16] performed arthroscopic and histologic analysis of patellar tendon autografts following ACL reconstruction. The knees of 23 patients underwent arthroscopy and biopsy from 3 weeks to 6.5 years postoperatively. They observed that human patellar tendon autografts were viable as early as 3 weeks with exception of the central biopsy at 3 weeks. They detected increased neovascularity, nuclear morphology, and fibroblastic activity in the human grafts as compared to the necrotic stage observed in animals. Ligamentization required up to 3 years to complete.

To determine the strength of an ACL substitute, researchers studied the mechanical properties of various graft sources. Clancy et al[13] studied the tensile strength of patellar tendon grafts in monkeys at 3, 6, 9, and 12 months postoperatively. Three animals at the first three follow-up periods and five animals at the final follow-up period underwent stress to failure testing. The results demonstrated patellar tendon grafts had regained 81% of their original tensile strength prior to transfer at 9 and 12 months following reconstruction and were 52% of the strength of the normal ACL at 12 months following reconstruction. The authors considered these results significant because Butler et al[17] had demonstrated that a third of the patellar tendon in humans had 191% of the strength of the ACL. Noyes et al[18] compared the mechanical properties of nine human ligament graft tissues obtained from young trauma victims (mean age 26 years). The tissues studied included the ACL, central and medial portions of the bone-patellar tendon-bone (BPTB), semitendinosis, fascia lata, gracilis, distal iliotibial tract, and the medial, central, and lateral portions of the quadriceps tendon-patellar retinaculum-patellar tendon. All tissues were subjected to high-strain-rate failure tests to determine strength and elongation properties. The BPTB graft was the strongest with a mean strength of 159% to 168% of that of an ACL. The strength of the substitute graft would theoretically affect the initiation of motion and strengthening activities during the rehabilitation process.

Controversy surrounded the safety of simple motion and other stresses as researchers attempted to identify strain imposed on the ACL during rehabilitation. Grood et al[19] studied the biomechanics of knee extension and the effect of cutting the ACL in human cadavers. They reported increased anterior tibial translation during knee extension from 30° of flexion to full extension. Arms and colleagues[20] studied ACL strain during knee ROM and simulated quadriceps contractions in human cadavers. Using a strain transducer, they showed that ACL strain decreased as the knee was passively flexed from 0° until 30°-35° where the ACL underwent minimal strain. Further flexion increased the strain to a maximum at 120 degrees. Isometric and eccentric quadriceps contractions significantly increased ACL strain through the first 45° of knee flexion while isometric contraction at flexion angles greater than 60° decreased ACL strain. Quadriceps activity beyond 60° was determined to be safe. The authors speculated that immobilization might not protect the graft if isometric quadriceps contractions occur. Henning et al[21] used an in vivo strain gauge to study the load-elongation of the ACL during rehabilitation exercises. Two subjects with acute grade II ACL sprains were utilized and the results were scaled to an 80-pound Lachman test. Cycling produced 7%, single leg half squat produced 21%, normal walking produced 36%, quadriceps contraction against 20 pounds of resistance at 45° produced 50% and at terminal extension produced 121%, and downhill running produced 125% as much elongation as an 80 pound Lachman test. The authors recommended that knee extension not be performed through a full ROM during the first year following ACL reconstruction. Strain data gave clinical insight to the stress produced on the ACL during various rehabilitation activities. Clinicians used this information to avoid certain exercises and thus protect the healing ACL.

However, there are no direct methods of knowing the limits of strain that are safe for a healing ligament or graft.

Rougraff and Shelbourne[22] suggested that stresses to the healing tissue that remained below failure threshold would be beneficial and that rehabilitation programs designed to limit stresses may negatively affect ultimate outcome. This postulation was supported by Hannafin et al[23] who performed an in vitro study on the effects of stress deprivation on canine tendon. Their results showed a significant decrease in tensile strength over 8 weeks. They suggested that stress may be necessary for optimal graft healing and collagen formation.

TRADITIONAL REHABILITATION

These basic science studies led to the belief that intra-articular graft healing was a long-term process that included a maturation phase in which the graft was necrotic and weak. In an effort to protect the graft, emphasis was placed on immobilization, extension limitation, restricted weight bearing, and delayed return to activity.

In 1981, Paulos et al[1] published the specifics and rationale of their postoperative rehabilitation program for patients following ACL reconstruction *(Figure 1)*. Although they openly stated that their rehabilitation program was based on preliminary findings,opinions and designed to protect all patients, many practicing clinicians quickly adopted this protocol.[2,23,24] The rehabilitation program consisted of five phases that included maximum protection (12 weeks), moderate protection (24 weeks), minimum protection (48 weeks), return to activity (60 weeks), and activity and maintenance.

During the maximum protection phase, patients were placed in a cast, nonweight- bearing (NWB) for 6 weeks in 30° to 60° of flexion. Based on animal research, they estimated healing ligament strength at less than 50% by 12 weeks. Full weight-bearing (FWB) was not allowed prior to 16 weeks. Quadriceps activity was limited through the first 24 weeks to minimize risk to the ACL, while emphasis was placed on hamstring strengthening. Running began approximately 9 to 12 months after surgery when the operative leg achieved 75% strength of the normal leg. The authors recommended a minimum of 9 months to return to full activity with most patients requiring at least a year.

A 1980 international survey performed by Paulos et al[1] revealed that 53% of responding knee experts initiated knee motion by 3 weeks. The authors were concerned that the early initiation of knee motion could disrupt attachment site fixation. Of those included in the survey, 75% recommended an immobilization position of 30-60 degrees. The mean time for FWB was 7.7 weeks. The authors cautioned progression to early weight-bearing due to animal studies that demonstrated early graft vascularization at 8 weeks. Full range of motion (ROM) was expected at 6 months by 88% of respondents and the mean time for maximum knee motion was 4.3 months. The majority (63% always, 22% sometimes) felt a brace should be used for protection. Most respondents allowed running by 6 months with the mean at 4.7 months. Mean time for return to full activity was 9.4 months.

TRENDS IN THE 1980'S

Many researchers continued to study graft remodeling and revascularization as graft integrity and viability following ACL reconstruction remained a concern. Studies challenged the standard treatment of immobilization following ACL reconstruction and showed the beneficial effects of immediate joint motion.[25,26] In turn, authors reported performing motion exercises sooner following reconstruction. Noyes et al[27] reported that utilization of early motion avoided knee stiffness and promoted full knee extension following ACL reconstruction. Their early motion program utilized continuous passive motion (CPM) during hospitalization. Upon discharge a knee splint was worn which allowed an immediate arc of 0° to 90° of flexion and the patient used the opposite leg to assist motion for 10 to 15 minutes every hour. In 1987, Noyes et al[28] studied the effects of early knee motion following open and arthroscopic ACL reconstruction. Eighteen patients with acute and chronic ACL deficiencies were randomized into two groups prior to surgery. The motion group started knee motion on the second postoperative day while the delayed motion group initiated motion on the seventh postoperative day. All other aspects of the rehabilitation program were the same. Results showed that CPM performed on the second postoperative day did not increase joint effusion or result in stretching of the ligamentous reconstruction as measured by a KT-1000 arthrometer at 6 months postoperatively. Although not significant, the early motion group also achieved increased mean knee extension and flexion values measured at 1, 2, 3, 4, and 12 weeks postoperatively. Despite the apparent benefits of early motion following ACL reconstruction, the authors were still concerned that utilization of a CPM after reconstruction would disrupt or loosen the graft.[29]

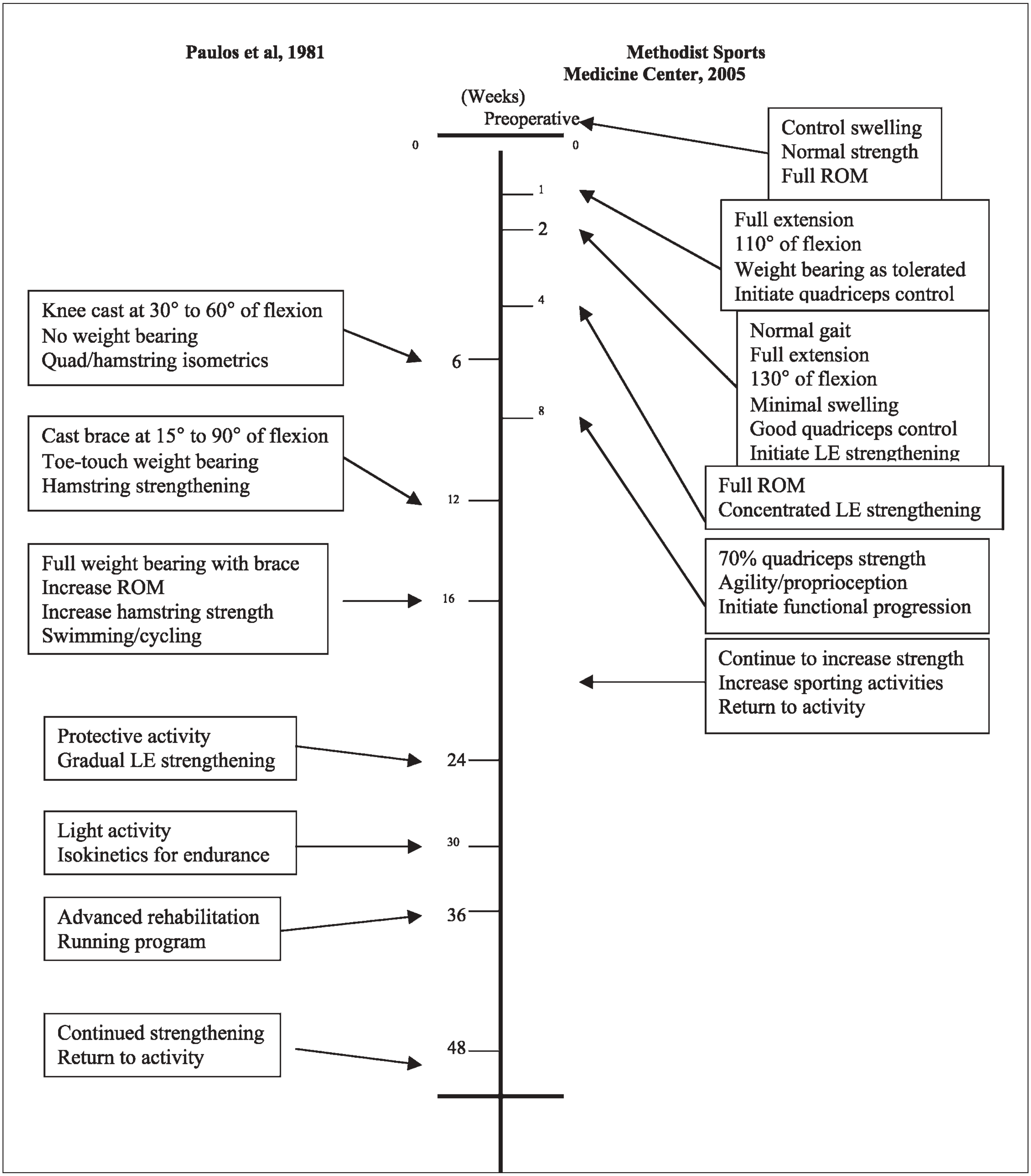

Figure 1. Comparison between traditional rehabilitation as described by Paulos et al[1] and the Methodist Sports Medicine Center Rehabilitation program.

In 1986, Bilko et al[30] published the results of a questionnaire taken at the ACL Study Group meeting in 1984. The survey results were compared to the results of the 1980 international survey by Paulos et al.[1] Analysis of 44 returned questionnaires indicated that more surgeons immobilized the knee between 30° and 60° of flexion, yet the length of time immobilized decreased. Of those who responded, 48% were immobilized between 1 and 3 weeks compared to 21% who were immobilized between 5 and 8 weeks. Isometric exercises were not prescribed as often during the 1st week postoperatively, while the use of electrical stimulation and isokinetics during rehabilitation occurred more frequently. The earliest time to full weight-bearing ranged from the 3 to 4 week period to 16 weeks. Less than 7% indicated regular use of continuous passive motion. Full ROM was expected at 3 months by 18% and 6 months by another 68% following ACL reconstruction. Only one surgeon responded that the minimum time for return to full activity was 6 months, while 95% reported return within 10 months postoperatively. All respondents allowed return to full activity by one year. Only 25% did not recommend a brace for return to play.

Despite achievement of good ligamentous stability, patients often experienced a spectrum of complications that included patellofemoral symptoms, quadriceps weakness, and limited ROM.[31-33] From 1982 to 1986, Sachs et al[34] prospectively followed 126 patients who underwent ACL reconstruction and were immobilized in 30° of flexion for 3 weeks. At one-year follow-up, quadriceps weakness was defined as less than 80% bilaterally and was present in 65% of patients which correlated positively with flexion contracture and patellar irritability. Flexion contractures ≥ 5° were present in 24% of patients and patellofemoral pain occurred in 19% of patients. Sachs et al[35] also published results from the San Diego Kaiser review series of 390 patients with ACL surgeries between 1983 and 1988. One year follow-up statistics revealed 3% of patients with postoperative graft impingement, 7% required manipulation, 20% had flexion contractures, 19% experienced patellofemoral pain, 62% demonstrated quadriceps weakness, 12% exhibited an effusion, and 10% required a secondary procedure within 1 year. To decrease the incidence of joint stiffness and flexion contracture, the authors recommended full ROM and no swelling at the time of surgery as well as immobilization of patients at 0° for 10 -14 days postoperatively.

Trends in ACL rehabilitation in the 1980's revealed earlier ROM and weight bearing.[36] Disagreeement was predominant in regard to the initiation of weight-bearing, full ROM, rehabilitation exercises, and return to play. The complication rate remained high during this time but decreased with initiation of earlier motion. It is the senior author's opinion that the rehabilitation programs which were published largely emphasized open kinetic chain (OKC) exercises and hamstring strengthening.[1,24,37]

ACCELERATED REHABILITATION

Rehabilitation of patients following ACL surgery at Methodist Sports Medicine Center initially followed many of the trends begun in the 1980's. In 1982, patients were placed in a cast for 6 weeks following ACL reconstruction. Due to flexion contractures, strict immobilization was replaced in 1983 with the immediate use of a CPM and a 30° removable splint. Like many clinics, the rehabilitation protocol was slightly modified from that used by Paulos et al .[1] Patients did not weight bear until 6 weeks, attain full motion until 4 months, or return to activity until 9 to 12 months postoperatively. By 1985, patients were placed in a 0° postoperative splint. Consequently, motion problems decreased while stability remained unchanged. In 1985, the staff studied patient compliance and found that good clinical results, such as full ROM, strength, stability, and return to activity, were not necessarily correlated with subjectively reported patient compliance (unpublished data). In fact, patients who were noncompliant actually had better results than those who complied with the rehabilitation program. Subsequently, a new criterion-based rather than time-based rehabilitation protocol was adopted at Methodist Sports Medicine Center by the end of 1986.

In 1990, Shelbourne and Nitz[2] published a clinically based article on accelerated rehabilitation of patients following autogenous bone-patellar tendon-bone (BPTB) ACL reconstruction. The accelerated program called for rapid advancement of goals and emphasized early full knee extension, quadriceps muscle leg control *(Figure 1)*, soft tissue healing, and normalized gait pattern. Patients were not immobilized following surgery. On day 1, CPM was initiated and weight bearing as tolerated was allowed without crutches. Strengthening exercises were predominantly closed kinetic chain (CKC) and OKC quadriceps exercises were minimized. Patients typically returned to light sports activities by 2 months and full activity between 4 and 6 months following reconstruction. Subjective and objective follow-up evaluations were routinely performed, as were isokinetic and KT-1000 evaluations beginning 5 to 6 weeks postoperatively. Shelbourne and Nitz[2] reported increased patient compliance, earlier return to normal function, decreased frequency of patellofemoral symptoms, and a significant decrease in the number of procedures required to obtain full knee extension.

Shelbourne and Nitz[2] reported a retrospective comparison of follow-up data on 138 patients who performed a traditional rehabilitation program following ACL reconstruction from 1984 to 1985 and 247 patients from 1987-1988 who performed the accelerated rehabilitation program following ACL reconstruction. Subjective knee ratings were similar for both groups from the time of reconstruction to 2-year follow-up. Isokinetic quadriceps strength tests revealed a quicker return of quadriceps strength in the accelerated group at each follow-up period from 4 months to 1 year. Likewise, analysis of KT-1000 scores revealed equal to or better scores than the traditional group at each follow-up comparison from 4 months to 1 year, which indicated no loss in knee stability. Furthermore, 12% of patients who performed the traditional rehabilitation program required surgical intervention to achieve full extension compared to 4% of patients in the accelerated program.

TRENDS IN THE 1990'S:
EVIDENCE FOR ACCELERATED REHABILITATION

The accelerated program was met with much resistance in the literature. Many authors were concerned that "aggressive" rehabilitation would lead to graft failure,[14,38] inappropriate graft strain,[39-43] or adversely affect articular cartilage.[40] Several authors cited that there was no evidence to support the safety of activities such as early FWB, jogging and agility drills by 5 to 6 weeks, return to sport at 4 to 6 months,[43-45] and were alarmed by the lack of long-term follow-up.[38,39,43,46] Devita et al[45] reported that gait mechanics were abnormal following accelerated rehabilitation while Hardin et al[47] suggested that individuals with hyperlaxity had an increased risk for instability following accelerated rehabilitation. Beynnon and Johnson[44] questioned the safety of accelerated rehabilitation citing the retrospective nature and possible bias as caution for clinical use.

Figure 2. Heelslides are used to attain knee flexion.

Accelerated rehabilitation has been previously described in detail.[2,48-52] The Methodist Sports Medicine Center rehabilitation program outlined in Figure 1 was largely based on the principles of the accelerated protocol.[2] The goal of the Methodist Sports Medicine Center rehabilitation protocol had always been to minimize postoperative complications and return the knee to a normal state as quickly and safely as possible. The protocol continued to be adapted and changed based on clinical experience and the current findings in the literature. With the emergence of evidence-based practice (EBP), much of the accelerated rehabilitation program following autogenous BPTB ACL reconstruction had been well supported in the literature. The term "accelerated" rehabilitation may no longer be appropriate or necessary due to the shift in rehabilitation trends over the past decade.

The Methodist Sports Medicine Center rehabilitation protocol was divided into 5 phases: preoperative, early postoperative, intermediate postoperative, advanced rehabilitation, and return to activity. The time frames presented with each phase were general in nature and based on clinical experience. Progression of patients between phases of rehabilitation were individualized decisions determined by achievement of goals and clinical reasoning.

Phase I: Preoperative

Phase I rehabilitation began immediately following ACL injury.[49] The goals of the preoperative period were to reduce swelling and restore normal motion, gait, and strength prior to surgery. Common exercises for flexion ROM included heel slides *(Figure 2)*, wall slides, and active/assistive flexion. Exercises for extension ROM included heel props *(Figure 3)*, prone hangs, and towel extensions. Once full ROM with minimal swelling was obtained, CKC strengthening was begun with exercises such as leg press, _ squats, step downs *(Figure 4)*, stationary bicycle, and step machines. This time frame also allowed for mental preparation and education of surgery and postoperative rehabilitation. Surgery was scheduled once these goals were attained. The patient underwent preoperative testing for postoperative comparison that included bilateral ROM, KT-1000 ligament arthrometry, isokinetic strength evaluation, and a single leg hop test on the non-involved extremity.[50-52]

De Carlo et al[50] reported a retrospective study of 169 patients who underwent autogenous BPTB ACL reconstruction for acute ACL injury. Patients who had reconstruction within the first week after injury had a significantly increased incidence of arthrofibrosis compared to patients who had reconstruction delayed 21 days or more. Patients who had delayed reconstruction also had better ROM and isokinetic strength scores at 13 weeks following reconstruction. Shelbourne and Foulk[53] performed a retrospective review of 143 patients who underwent autogenous BPTB ACL reconstruction within 3 months of injury. Patients were divided into two groups based on when they elected to have surgery. Group 1 delayed surgery a mean of 40 days after injury while group 2 had surgery a mean of 11 days after injury. Results of isokinetic testing determined that patients who delayed ACL reconstruction had significantly better quadriceps strength at 2 and 4 months postoperatively than those who underwent acute surgery. Cosgarea et al[54] and Wasilewski et al[55] have also confirmed earlier return of motion and strength following delayed ACL reconstruction. Two studies have reported that timing of surgery had no effect on extension loss.[56,57] However, both authors defined full extension as 0° rather than the ROM prior to surgery.[56,57] Regardless of the time from injury, the senior author believes the condition of the knee prior to reconstruction (minimal swelling, full hyperextension, near normal strength, and normal gait) were directly correlated with the ability to regain early motion and strength postoperatively.

Figure 3. A heel prop is used to allow the knee joint to hyperextend.

Figure 4. The step-down exercise is used to develop quadriceps strength.

Udry et al[58] studied psychological readiness of the patient undergoing ACL reconstruction. They found that adolescents reported higher preoperative mood disturbance levels compared to adults. However, adolescents also reported higher levels of psychological readiness for surgery than adults. Shelbourne and Rask[59] reported that patients who had a second ACL procedure for the opposite knee experienced a smoother transition following reconstruction than with the initial procedure. For this reason, a thorough preoperative education was incorporated for all patients. These factors are important to consider because of the effort, motivation, and understanding required of postoperative rehabilitation.

Phase II: Early Postoperative

Immediately following surgery, the reconstructed knee was placed in a cold compression cuff with the leg in a CPM machine. Range of motion, quadriceps control, and weight-bearing as tolerated were initiated the day of surgery. The goals for the first postoperative week were to control swelling, obtain full hyperextension, increase passive knee flexion to at least 110°, and establish good quadriceps leg control. The cold compression cuff remained on the knee at all times except when patients performed ROM exercises. The patient remained lying down as much as possible except when exercises were performed or for personal hygiene. Extension ROM exercises, such as heel props and towel extensions, were performed for 10 minutes hourly during the day. Flexion was initiated with the knee rested in the CPM machine set to 110° and held for 10 minutes, four times daily. Early leg control was accomplished with quadriceps setting, straight leg raises, and active knee hyperextension.

By the end of the second postoperative week, the patient should have been able to demonstrate normal gait, full passive extension, 130° of flexion, and good quadriceps leg control. During this week, patients added prone hangs (1-3 lbs could be added if extension was tight) to their daily ROM exercises. Patients were encouraged to stand with their weight over their reconstructed knee with the quadriceps contracted, which locked the knee into full hyperextension. Gait training was necessary if the patient ambulated with a limp or without a normal heel-to-toe pattern. If the patient had full knee hyperextension and ambulated normally, strengthening exercises could be initiated which included seated knee extension from 90° to full terminal knee extension and bilateral half squats.

Lower Extremity Functional Progression for Court Sports

1. Heel raises 10 times (injured leg)
2. Walk at a fast pace full court
3. Jump on both legs 10 times
4. Jump on the injured leg 10 times
5. Jog in a straight line full court
6. Jog around the entire perimeter of the court two times
7. Sprint at 1/2, 3/4 and full speed from the baseline to half court
8. Run figure 8's at 1/2, 3/4, and full speed from the baseline to half court
9. Triangle drills – sprint baseline to half court, backward run to the baseline, defensive slides along baseline, both directions
10. Cariocas (cross-over drill) completed at 1/2, 3/4, and full speed
11. Cutting completed full court at 1/2, 3/4, and full speed

Figure 5. Functional progressions specific to the patient's sport are employed to establish whether or not the patient is ready to return to activity.

Shelbourne et al[60] performed a prospective trial which compared the effectiveness of different methods of postoperative cryotherapy to decrease pain in 400 patients following autogenous BPTB ACL reconstruction. Patients who used a cold compression device had a significantly shorter hospitalization stay compared to patients who used a thermal blanket or ice bag. They used significantly less oral and injectable narcotics compared to patients who used an ice bag. Noyes et al[61] conducted a prospective study of early motion versus delayed motion exercises in 18 patients following ACL reconstruction. Subjects in the early motion group began CPM on the second postoperative day while subjects in the delay motion group were braced in 10° of extension and began CPM on the seventh postoperative day. The results showed no deleterious effects of early motion with regard to knee laxity, joint effusion, hemarthrosis, ROM, use of pain medication, and length of hospital stay. The use of cold compression, CPM, and early active motion allowed for elevation of the leg, patient comfort, and predictable return of motion.

Initially, many authors were hesitant to attain full extension in the early postoperative period.[62] These concerns were based on biomechanical studies that showed maximal flexion and extension of the knee caused increased stress on the intact ACL.[63] However, many authors had reported that gaining extension immediately postoperatively decreased the frequency of flexion contractures.[2,27,28,34,54,64] Rubinstein et al[65] reviewed the effects of restoring full knee hyperextension immediately following autogenous BPTB ACL reconstruction. Subjects were grouped according to the degree of hyperextension. Group 1 consisted of 97 patients who hyperextended an average of 10° (8°-15°) and group 2 consisted of 97 patients who hyperextended an average of 2° (0 - 5°). No significant differences in KT-1000 arthrometer manual maximum side-to-side scores between groups were found. The authors determined that restored full knee hyperextension immediately postoperatively did not adversely affect stability of the knee.

Several authors had voiced concern that early weight-bearing may have caused excessive forces that harm the graft or fixation and suggested 4 to 6 weeks of crutches to allow for bone healing.[43,62,66,67] However, Arnoczky[68] reported that a biologic graft was the strongest the day it was placed inside the knee. A prospective, study by Tyler et al[69] sought to determine the effect of immediate weight-bearing after autogenous BPTB ACL reconstruction. Forty-nine subjects were randomized into two groups. Group 1 underwent immediate weight-bearing as tolerated while group 2 was nonweight-bearing for 2 weeks. Results showed that immediate weight-bearing after ACL reconstruction resulted in a lower incidence of anterior knee pain, greater vastus medialis oblique electromyography activity, and no effect on knee stability at a mean follow-up of 7.3 months.

Phase III: Intermediate Postoperative

The third and fourth week following reconstruction was the intermediate postoperative phase. During this period, strengthening was initiated cautiously as full ROM was obtained. Strengthening progressed as long as minimal swelling and full ROM were maintained. Exercises were predominantly unilateral, high repetition/low resistance, and CKC exercise during this period and included step downs, leg press, leg extension, and half squats. At the end of 4 weeks, patients underwent passive ROM testing and completed their first postoperative isokinetic strength evaluation and KT-1000 ligament arthrometer tests.

Strain studies indicated that CKC exercises allowed increased muscle activity without subjecting the ACL to increased strain values.[70-72] A prospective study by Bynum et al[73] compared OKC versus CKC exercises during rehabilitation following authogenous BPTB ACL reconstruction. Ninety-seven patients were randomized to the OKC and CKC protocols. Results at a mean follow-up of 19 months demonstrated that CKC exercise following ACL reconstruction resulted in less patellofemoral pain and better subjective scores than OKC exercise. Subsequently, the authors reported using CKC exercise exclusively following ACL reconstruction. A prospective study by Mikkelsen et al[74] compared CKC versus combined CKC and OKC exercise initiated 6 weeks after ACL reconstruction. Forty-four patients were randomized into the two groups. Follow-up at 6 months indicated that the addition of OKC exercise produced a significant improvement in quadriceps strength, earlier return to sport, and no increased KT-1000 measurements. Although caution was used with full arc OKC exercise, the Methodist Sports Medicine Center protocol included integration of both OKC and CKC exercises.

Phase IV: Advanced Rehabilitation

Weeks five through eight comprised the advanced rehabilitation phase. The emphasis of this phase was increased strength and initiation of early sports activities. The patient continued to maintain full ROM and advanced strengthening to low repetition/high resistance as indicated. Once patients demonstrated 70% quadriceps strength via isokinetic testing, they performed light agility drills and proprioceptive activity that included a running progression, lateral slides, crossovers, and single leg hopping. If a joint effusion was present, it was carefully monitored as activity increased. An activity-specific functional progression, such as shooting baskets or dribbling a soccer ball, was initiated near the end of this period. At the end of 8 weeks, the patients were evaluated to assess ROM, tested with the KT-1000 ligament arthrometer, performed an isokinetic strength evaluation, and completed a subjective questionnaire.

In 1993, Barber-Westin and Noyes[39] reported serial KT-1000 measurements on 84 patients following BPTB allograft ACL reconstruction and controlled rehabilitation for chronic ACL deficiency. Arthrometer measurements were obtained on each patient for at least 2 years following surgery. Of those patients with abnormal anterior-posterior displacements greater than 2.5 mm, 86% were first detected during the intensive strength training or return to sports phases of rehabilitation. In 1999, Barber-Westin et al[40] reported a subsequent observational study of 142 patients following ACL reconstruction that used a rehabilitation program similar to the previous study. However, this group of subjects used a BPTB autograft rather than an allograft. They found no association between abnormal displacements and the phase of rehabilitation.

Shelbourne and Davis[75] followed 603 patients who underwent autogenous BPTB ACL reconstruction and participated in a sports agility program at a mean of 5.1 weeks. These patients were evaluated to determine if program effected knee stability. Patients were required to have full hyperextension, knee flexion to 120°, and at least 60% quadriceps strength compared to the normal leg. The KT-1000 manual maximum arthrometer scores revealed that 92.7% of patients at a mean of 5 weeks and 93.2% of patients at a mean follow-up of 24 weeks had displacement differences of 3 mm or less. The results showed that early return to sports agility activities did not compromise graft integrity measured 24 weeks following ACL reconstruction.

Phase V: Return to Activity

Return to activity was very individualized and was designed to match the patient's goals. The patient continued to increase strength and increase the intensity and duration of athletic activities. A functional progression *(Figure 5)* that followed a half to three-quarter to full speed progression of sport-specific activities was incorporated in this phase. The patient achieved 85% quadriceps strength and completed a functional progression program prior to return to full athletic activity. While some patients returned to activity as early as 2 months, typically patients returned to full activity between 4 and 6 months after ACL reconstruction.

Many authors continued to base return to activity guidelines on histological studies that reported full maturation and required 12 months to complete.[76] However, Rougraff et al[16] reported that ligamentization could require up to 3 years to complete. Glasgow et al[77] studied the effects of early (5 months) versus late (9 months) return to vigorous cutting activities on outcome in 64 patients following patellar tendon autograft ACL reconstruction. Return to vigorous activity was based on a minimum of 8 weeks postoperation, negative Lachman test, absence of effusion, and patient desire to return. At a mean follow-up of 46 months, no differences were found in KT-1000 scores, subjective evaluations, or isokinetic strength. Interestingly, in a review of 1288 patients who underwent autogenous BPTB ACL and accelerated rehabilitation, Shelbourne and Davis[75] reported that more patients tore their normal, contralateral ACL (4.4%) than their reconstructed ACL (2.4%). They proposed that graft failure was not the result of a weakened graft, but rather the consequence of normal return to sport.

In 1995, Shelbourne et al[78] reported KT-1000 manual maximum difference scores in a 2 to 6 year follow-up of 209 patients after autogenous BPTB ACL reconstruction and accelerated rehabilitation. The mean KT-1000 score was 2.06 mm at full ROM and 2.10 mm at a mean 2.7 year follow-up. In 1997, Shelbourne and Gray[79] reported objective data on 806 patients and subjective data on 948 patients in a 2 to 9 year follow-up after autogenous BPTB ACL reconstruction and accelerated rehabilitation. Of those patients who underwent acute reconstruction, the mean manual maximum KT-1000 arthrometer difference was 2.0 mm with 90% of patients less than or equal to 3 mm and 98% of patients less than 5 mm of laxity. No joint space narrowing was seen in 94% of patients, isokinetic quadriceps evaluation revealed 94% strength, mean motion was 5° of hyperextension and 140° of flexion, and mean subjective modified Noyes questionnaire[87] score was 93.2 out of 100 possible. In 2000, Shelbourne and Gray[79] reported on the effects of meniscus and articular cartilage status on autogenous BPTB ACL reconstruction and accelerated rehabilitation in a 5 to 15 year follow-up. Of those patients with both menisci present and normal articular cartilage at the time of surgery, 97% had normal or near normal radiographs. Based on these findings, evidence supported that accelerated rehabilitation following autogenous BPTB ACL reconstruction produced excellent long-term results without affecting long-term stability.

Trends in ACL rehabilitation in the 1990's revealed remarkable changes compared to the 1980's. Many authors began adopting protocols similar to the accelerated program.[80-85] The rehabilitation programs were characterized by preoperative rehabilitation, immediate ROM and weight bearing, full passive knee extension, and functional exercise. Meanwhile, some authors continued to share concerns regarding the wide scale use of these new protocols, particularly in specific patient groups or with specific graft sources.[40,45,46]

ACL REHABILITATION IN THE 2000'S: EVIDENCE-BASED PRACTICE

Recently, the buzzword in the physical therapy profession has been "evidence-based practice." Evidence based practice is a very positive trend that may ultimately result in improved quality and effectiveness of patient care. Sackett et al[86] defined EBP as "the integration of best research evidence with clinical expertise and patient values." Evidence based practice could be the trend that defines ACL rehabilitation in the 2000's.

Several authors[41,44,70,87] have published well-conducted research on the strain behavior of the ACL during common rehabilitation activities. A comprehensive database has been compiled based on peak strain values in which the authors used to design rehabilitation programs to be compared in a prospective, randomized, double-blind trial. The results of these studies will help delineate rehabilitation programs that are safe for a healing ACL graft. A need exists for prospective, randomized, blinded clinical trials to compare accelerated rehabilitation with more conservative rehabilitation before accelerated rehabilitation can be considered safe and appropriate.[88]

Recently, Beynnon et al[89] reported the results of a prospective, randomized, double-blind study comparing accelerated versus nonaccelerated rehabilitation in 22 patients following BPTB ACL reconstruction. The rehabilitation programs were based on their previous work of ACL strain data during rehabilitation activities. Exercises that had been shown to produce significant strain to the ACL were initiated earlier in the accelerated program and delayed in the nonaccelerated program. Exercises that did not produce significant ACL strain were initiated in both rehabilitation programs during the same time frame. The accelerated program, characterized by early unrestricted weight-bearing and early use of quadriceps-dominated exercises, lasted 19 weeks and return to sports was possible by 24 weeks while the nonaccelerated program lasted 32 weeks and return to sports was possible also at 32 weeks. At 2-year follow-up, their results demonstrated no difference in anterior knee laxity between accelerated and nonaccelerated rehabilitation. The authors also found that both programs produced the same outcomes in clinical assessment, patient satisfaction, functional performance, and articular cartilage metabolism. Furthermore, total compliance measured at the end of each program was significantly less in the nonaccelerated group.

Evidence based practice has not been limited to prospective, randomized, blinded clinical trials.[90] While the authors agree that prospective, randomized, blinded clinical trials are the gold standard and large studies of this nature are required for best evidence practice, the difficulty most clinicians face in performance of such studies must be acknowledged. Prospective long-term outcome studies may also be conducted to gain insight into the effectiveness of clinical intervention.

To date no studies have been published that have determined conservative rehabilitation following ACL reconstruction to have produced better outcomes or long-term stability than those reported with accelerated rehabilitation. Therefore, the current evidence supports the use of the more physiologic progression following BPTB ACL reconstruction.

While research evidence has been a very important part of EBP, it is the senior author's opinion that clinical expertise and patient values are equally important components of EBP for quality patient care. Salter[91] reported that the biological concept of CPM for synovial joints was based on clinical observation and deduction. In 1970, the concept of CPM was introduced which was contrary to the initial thought process of joint immobilization for disease or injury.[91] The evolution of the Methodist Sports Medicine Center rehabilitation protocol following ACL reconstruction was based on clinical experience and listening to patients.[2,49-51] In 1990, accelerated rehabilitation was the antithesis of traditional rehabilitation following ACL reconstruction.[2]

The clinician must utilize clinical reasoning skills and individualize the care of each patient. No specific exercises or parameters exist for exercise intensity or duration that have been proven to lead to successful outcomes. Guidelines for early application of strain to the healing ACL have not been published. The Methodist Sports Medicine Center rehabilitation protocol the authors have presented has adhered to the basic principles of rehabilitation. Patients increased activity if they had attained full ROM, exhibited minimal effusion and pain, had a normal gait, and demonstrated good leg strength measured isokinetically (quadriceps deficit of ≤30%). The condition of the knee dictated rehabilitation. Patients were not forced to return to activity. Only when the patient was physically and mentally ready was return to activity considered. In addition, the use of a functional progression program allowed the patient and the physical therapist, athletic trainer and, in rare instances, the coach to determine if an athlete was ready to advance.

RE-EMPHASIS IN ACL REHABILITATION

Many researchers have attempted to replicate the accelerated Methodist Sports Medicine Center rehabilitation protocol[45,46,91] or currently utilize a similar protocol. For this reason, the authors felt that it was important to clear some misconceptions and re-emphasize some key points of the Methodist Sports Medicine Center rehabilitation protocol.

The preoperative period was vitally important for successful outcome following ACL reconstruction.[49,50,52,93] Patients were required to have full ROM including hyperextension, minimal effusion, good quadriceps strength via isokinetic testing, and normal gait prior to reconstruction. Once these goals were met, surgery was scheduled at a time that was convenient for the patient to allow restricted activity during the first postoperative week.

The emphasis of the first postoperative week was the minimization of swelling.[49,59,60] If swelling could be prevented, motion and strengthening would not be inhibited. Although immediate full weight bearing as tolerated with crutches was allowed, activity was not unrestricted. The patients were instructed to remain supine with the leg in the CPM machine except when performing exercises or personal hygiene.[50] The ability to prevent swelling during the first postoperative week greatly impacted the progression of return to activity.

Restoration of motion should be aimed to achieve motion equal to the opposite extremity. Normal motion was often thought of as 0° to 135°.[46,56,57,66,89] However, a study by De Carlo and Sell[94] of 889 preseason athletes found that 96% of individuals demonstrated some degree of hyperextension. The mean ROM was 5° of hyperextension and 140° of flexion for males and 6° of hyperextension and 143° of flexion for females. If the patient had not achieved full ROM, especially hyperextension, equal to the opposite side, the return of normal gait, function, and knee biomechanics would have been inhibited. The importance of obtaining full hyperextension postoperatively has been well documented.[2,16,27,28,34,54,64]

The Methodist Sports Medicine Center rehabilitation protocol was criterion-based.[49] The time frames given were used as guidelines and were not absolute. Advancement to the next phase depended on the condition of the knee and completion of the goals of the previous phase. The initial phases of the program were very similar for all patients in an attempt to restore normal motion, gait, and strength. The latter phases of the program were much more individualized in an effort to return patients to their previous level of function.

CONCLUSION

Over the past two decades, rehabilitation of a patient after an ACL injury has made a dramatic shift toward better patient outcomes and quicker return to activity. In their respective times, the traditional and accelerated rehabilitation models have both given clinicians a sound framework for treating patients as well as stimulated further research. A solid base of evidence exists in the literature to support accelerated rehabilitation as both safe and effective. As EBP and the call for prospective, randomized clinical research continues, the continued progress in treating this injury is exciting. Furthermore, clinicians are urged not to lose sight of the clinical reasoning and deduction that assisted in the evolution of the current science of ACL rehabilitation.

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CASE REPORT

USE OF KNEE EXTENSION DEVICE DURING REHABILITATION OF A PATIENT WITH TYPE 3 ARTHROFIBROSIS AFTER ACL RECONSTRUCTION

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ABSTRACT

Background. Arthrofibrosis is a frequent complication following rehabilitation of a patient with anterior cruciate ligament (ACL) reconstruction. Although prevention is the best treatment, little information exists within the literature regarding the management and rehabilitation intervention for arthrofibrosis. In this case report a rehabilitation program in the treatment of a patient with arthrofibrosis is described.

Objectives. To identify the importance of discrete measures of knee range of motion in the knee of a patient following ACL reconstruction in order to help prevent postoperative complications.

Case Description. The patient was an 18-year-old female who sustained an ACL and medial collateral ligament (MCL) injury in a basketball game and underwent an ACL reconstruction with an ipsilateral patellar tendon graft. The patient developed arthrofibrosis and, despite traditional physical therapy of therapeutic exercise and manual therapy, the patient continued to complain of pain, stiffness, limited activities of daily living, and the inability to participate in competitive sports. This patient used a knee extension device as part of her rehabilitation program.

Outcomes. The patient was able to obtain knee extension and flexion equal to her opposite normal knee. Upon completion of the rehabilitation program, the patient returned to full activities of daily living and competitive sports.

Discussion. Increasing and maintaining knee extension that is equal to the opposite normal knee is an important component in the successful outcome for the patient after ACL reconstruction. The use of a knee extension device may provide an effective rehabilitation intervention in the treatment of arthrofibrosis.

Key Words: arthrofibrosis, anterior cruciate ligament, rehabilitation

INTRODUCTION

Arthrofibrosis is an abnormal proliferation of fibrous tissue in and around a joint that can lead to loss of motion, pain, stiffness, muscle weakness, swelling, and limited activities of daily living. This condition can occur after an injury, or more commonly, after surgery.[1-12] Arthrofibrosis remains a common postoperative complication after anterior cruciate ligament (ACL) reconstruction despite the choices of graft selection. Patellar tendon grafts, hamstring grafts, and allografts are the most commonly used grafts selected for ACL reconstruction, and arthrofibrosis has been found to occur after all three. While a greater incidence of arthrofibrosis occurs with a patellar tendon graft, this condition continues to be prevalent in patients who received hamstring grafts and allografts, as well.[13,14]

Shelbourne et al[10] classified different types of arthrofibrosis in the knee based on the loss of knee extension, flexion, or both; the location of scar tissue formation intra-articularly; and the mobility and location of the patella *(Table 1)*. Prevention of arthrofibrosis is the preferred treatment and is possible with a structured rehabilitation program.[12] However, once arthrofibrosis has occurred, the treatment approach widely varies. Numerous published surgical reports exist regarding the cause and treatment of arthrofibrosis, but the rehabilitation programs are poorly defined.[1,3,5-7,9] For the physical therapist, even fewer guidelines exist with no consistent consensus among researchers as to the most effective treatment and postoperative

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Table 1. Classification of Arthrofibrosis.

TYPE	EXTENSION	FLEXION	PATELLAR MOBILITY
Type 1	<10° extension loss	Normal flexion	Normal
Type 2	>10º extension loss	Normal flexion	Normal
Type 3	>10º extension loss	>25º flexion loss	Decreased
Type 4	>10º extension loss	>30º flexion loss	Decreased and patella infera

rehabilitation.

The importance of obtaining and maintaining knee extension following ACL reconstruction is well documented in the literature.[1,4,10-12,15] Most treatment approaches for arthrofibrosis include surgical intervention followed by extension casting and "aggressive" physical therapy. Published reports discuss the use of serial casting, "drop out" casts and daily physical therapy.[8,10] This approach is often a time consuming event requiring daily cast changes and multiple visits to the clinic or hospital. However, the best treatment approach in achieving range of motion (ROM) after surgical intervention requires further investigation. Many times, patients with arthrofibrosis will undergo multiple surgeries and extended lengths of time in physical therapy, which can become very costly and time consuming.

The purpose of this case report is to describe the use of a knee extension device in the treatment of a patient with Type 3 arthrofibrosis. In this case a unique knee extension device was used as part of a home exercise program.

Table 2. Order of events following previous treatment.

EVENT	DATE	RIGHT KNEE ROM
Date of Injury	10-28-03	
ACL Reconstruction	12-09-03	0-0-45°
Manipulation	02-06-04	0-3-90º
Manipulation	03-22-04	0-10-108°
Follow-up appointment	05-13-04	0-7-120º

CASE DESCRIPTION

The patient was an 18-year-old female who tore her right ACL and medial collateral ligament during a basketball game on 10-28-03. She was evaluated by an orthopedic surgeon and placed in a knee brace that was locked at 30°. The patient was instructed by the physician to perform quadriceps muscle contractions and straight leg raise exercises. She underwent medial collateral ligament repair and ACL reconstruction using an ipsilateral patellar tendon graft on 12-09-03. After surgery, the patient's knee was kept in extension by a knee brace and she was limited to toe touch weight bearing for four weeks.

The patient began formal physical therapy for ROM and patellar mobilization on 12-31-03 and was advised by her physician to continue to wear the knee brace locked at 0° to 90°. Due to the slow progress in ROM, the patient underwent a right knee manipulation and arthroscopy on 02-06-04. After surgery, the patient continued with physical therapy for ROM exercises and was prescribed methylprednisolone (steroid for inflammation). Over the next month, the patient had her knee aspirated twice, was placed on rofecoxib (non-steroidal anti-inflamatory – NSAID), and repeated a dose of methylprednisolone. The patient continued to complain of pain and stiffness in her right knee. As of 03-19-04, her right knee ROM was still significantly limited at 0-10-108°.

The patient underwent a second right knee manipulation and arthroscopy on 03-22-04 *(Table 2)*. Postoperatively, the patient was placed on prednisone (steroid for inflammation) and issued a continuous passive motion (CPM) machine to assist with ROM. Upon follow up, the patient was diagnosed with arthrofibrosis. She was instructed to continue with physical therapy and placed on cyclobenzaprine, a muscle relaxer. She additionally received bupivacaine (analgesic for pain) injections prior to physical therapy appointments to help make her physical therapy more tolerable. She was attempting to run and bike but continued to have significant pain and stiffness. The patient was then referred to the Shelbourne Clinic at

Methodist Hospital for a second opinion on examination and treatment of her knee on 05-25-04.

Initial Physical Therapy Examination

Physical examination showed that the patient had an antalgic gait and was walking with a bent right knee. She had right quadriceps atrophy. The patient's knee had a mild effusion, good patella mobility in all directions, a negative Lachman test, negative posterior drawer, and negative varus and valgus laxity with testing. The patient felt no tenderness to palpation over the medial collateral ligament or the patellar tendon. She was able to perform a leg raise with a bent knee and significant extension lag. Plain radiographs were read as normal.

Range of motion measurements were taken using a goniometer as described by Norkin.[16] ROM measurements were recorded as A-B-C, with A being the degrees of hyperextension, B indicating lack of extension from zero, and C documenting degrees of flexion.[17] Her right knee ROM was 0-10-110° vs. her normal left knee 10-0-150°, which means she was lacking 20° of extension and 40° of flexion.

The International Knee Documentation Committee subjective knee form (IKDC) outcome instrument was used to assess the patient's current condition.[18] The initial score on the IKDC was 41/100 and is representative of a significant amount of disability.

The patient was diagnosed with Type 3 arthrofibrosis. The patient had been undergoing regular physical therapy in her home town three times per week since her ACL reconstruction. After discussing the details of the physical therapy sessions, it became apparent that the focus of the rehabilitation program had been on strengthening and not ROM. Therefore, the present focus was to try non-operative methods to maximize her knee ROM and restore knee symmetry. The goals of physical therapy were to increase right knee ROM equal to her left knee, decrease swelling, restore a normal gait pattern, increase leg strength equal to her left knee, and return to normal activities of daily living and eventually full competitive basketball.

Physical Therapy Intervention

The loss in knee extension is more problematic and causes more limitations than a loss of knee flexion.[1,8] Aglietti et al[1] showed that patients who have better knee ROM before surgery have a better prognosis and outcome after surgical intervention. Therefore, the initial plan of care focused on treating the knee extension loss. Paulos et al[8] showed that it is difficult to obtain and maintain both flexion and extension at the same time and achieving extension should be a priority. The treatment was initiated to focus on increasing knee extension only. Most uninjured, normal knees have some degree of hyperextension. De Carlo and Sell[17] found normal knee extension to be 5° of hyperextension in males and 6° of hyperextension in females. Normal knee ROM is defined as ROM equal to that of the noninvolved limb to include the measurement for hyperextension. The patient's normal, uninvolved knee extension measured 10° of hyperextension. Therefore, our goal was to maximize knee extension equal to the opposite normal knee.

A knee extension device (Elite Seat, Kneebourne Therapeutics, Noblesville, IN) was used that would stretch the knee into hyperextension *(Figure 1)*. The second author (KDS) is a part owner of Kneebourne Therapeutics which designed and developed the knee extension device. This device is patient controlled and provides a low load, long duration stretch.[19] The patient was issued and instructed to use the extension device for 10 minutes 3-4 times per day followed by additional knee extension exercises. These exercises included a towel stretch and heel prop exercises and active terminal knee extension while standing. The towel stretch is an exercise that focuses on increasing extension and forcing the knee into knee hyperextension *(Figure 2)* . The patient was advised in performing a heel prop and it was to be performed whenever the patient was sitting *(Figure 3)*. She was also instructed to stand on the involved extremity and attempt to extend the knee into a locked out posi-

Figure 1: Elite Seat: The Elite Seat is a knee extension device used to increase knee extension.

tion by an active quadriceps contraction *(Figure 4)*. This exercise assisted in maintaining the extension acquired from the previous exercises. All exercises were performed three times per day. The patient received instruction in gait training and was encouraged to walk full weight bearing with a normal, symmetrical gait pattern. Finally, she was issued and instructed in a cold/compression device (Cryo/Cuff, Aircast Inc., Summit, New Jersey, USA) to help control swelling and soreness.

Figure 2: Towel Stretch: The towel stretch exercise is performed to increase knee extension. A towel is placed around the ball of the foot and the opposite hand holds down the distal part of the thigh. The patient pulls the towel up bringing the knee into hyperextension.

Given that the patient lived approximately 5 hours of driving time from the clinic, she was set up on a home exercise program as described previously to focus on increasing and maximizing her involved extremity knee extension. Her progress was monitored through phone calls. Two weeks later she returned for a follow-up evaluation and presented with increased ROM. Her right involved knee measurement was 5-0-110° vs. 10-0-150° in the left normal knee. On physical examination, she was able to perform a straight leg raise and an active heel lift *(Figure 5)*; however, this activity was not equal to the opposite knee. The patient's knee had a mild effusion and she walked with a slightly bent knee. The patient reported that her knee was still very sore. The patient was advised to continue with her current home exercise program focusing on increasing her knee extension until she felt she was no longer making improvements.

Figure 3: Heel Prop: The heel prop is performed by placing a bolster under the patient's heel allowing the knee to fall into hyperextension.

The patient returned 2 weeks later (1 month after her initial visit) to check her progress following this new treatment. She felt she had maximized her knee extension at that time and was feeling most of her discomfort in the anterior aspect of the knee while using the knee extension device and performing the exercises. Upon physical examination, she continued to walk with a bent knee and had a mild effusion. Her ROM measured the same as her previous visit, still lacking both extension and flexion. She continued to have pain with walking, stairs and activities of daily living. The patient's desire was to return to high-level sports and she planned on playing basketball at a college later that year. Given that her knee was still lacking ROM and she was having pain and difficulty with activities of daily living, the patient elected to undergo an arthroscopic scar resection as recommended by the physician.

Surgical Intervention

The patient underwent an arthroscopic scar resection on 07-19-04, approximately 6 weeks after her initial presentation to the present clinic *(Table 3)*. Informed consent was obtained and the rights of the subject were protected for a study in the follow up of patients undergoing knee arthroscopy. She underwent the surgical procedure as described by Shelbourne et al[10] for Type 3 arthrofibrosis.

The patient was kept overnight in the hospital and received intravenous Toradol for inflammation and pain control. An anti-embolism stocking was applied to the patient's leg and the leg was elevated in a CPM machine to help prevent postoperative swelling. She was also placed in a CryoCuff (Aircast Inc., Summit, New Jersey, USA) to assist in preventing a hemarthrosis.

Post Surgical Physical Therapy Intervention and Examination

On the day of surgery, exercises for extension were immediately initiated. The knee extension device was used for 10 minutes, followed by 10 towel stretch exercises, and quadriceps activation to achieve and maintain an active heel lift. She followed this exercise with 10 straight leg raises to maintain good leg control and avoid quadriceps inhibition. These exercises for knee extension were performed six times per day. The patient was on bed rest for the first three days postoperatively to minimize swelling. Bed rest is an important concept after surgery since evidence exists that a hemarthrosis may contribute to an inhibitory effect on the quadriceps and hamstrings muscles resulting in muscle atrophy.[20] Early quadriceps muscle activation plays a key role in achieving and maintaining knee extension.[8] Therefore, although the patient was on bed rest to minimize swelling, she was performing a regular exercise program to achieve and maintain full terminal hyperextension equal to the opposite knee. Full weight bearing with a normal gait pattern was emphasized and allowed for restroom privileges only.

Figure 4: Standing knee lock-out: The patient shifts his/her weight to the involved extremity and forces the knee into hyperextension by a quadriceps contraction.

The patient was discharged from the hospital to a nearby hotel. Prior to discharge, her ROM was 10-0-90° in the right involved knee versus 10-0-150° in the left knee. She had a moderate effusion and walked full weight bearing with a slightly antalgic gait pattern. The patient was discharged from the hospital with a home exercise program. She was to remain supine in the CPM with continuous use of the cold/compression device. Six times throughout the day, she took her leg out of the CPM machine, removed the cold/compression device and performed the exercise program, which included the extension device for 10 minutes, towel stretch exercises followed by active quadriceps muscle activation 10 times, and straight leg raise exercises 10 times. The patient then reapplied the cold/compression device and placed her leg back in the CPM machine. Full weight bearing and a normal gait pattern was encouraged and emphasized for restroom privileges only.

Figure 5: Active Heel Lift: The patient is able to lift his/her heel off the table and make the knee go into hyperextension by contracting the quadriceps muscle.

At three days postoperatively, she returned to the clinic to have her ROM and progress evaluated. She continued to achieve full passive terminal hyperextension equal to the opposite knee, an active heel lift, a straight leg raise, and her knee had a moderate effusion. Knee flexion exercises were instituted because she had excellent leg control and equal knee extension. She was instructed in heel slide and wall slide exercises and was told to discontinue flexion exercises if she noted any loss in knee extension. She was instructed to continue to use the extension device and perform all exercises 3 to 5 times per day. She was told to perform a heel prop exercise when sitting and to stand on the involved extremity forcing the knee locked out by an active quadriceps muscle contraction when standing.

At 10 days postoperatively she had maintained her full passive terminal hyperextension equal to the opposite normal knee, an active heel lift, and was walking with a normal gait. Her knee had a mild effusion and ROM measured as 10-0-125° in the right involved knee versus 10-0-150° in the left normal knee. She was instructed to continue to focus on perfect knee extension and to increase her knee flexion until she could sit on her heels equally and comfortably *(Figure 6)*. No strengthening exercises were initiated so that the focus continued to be on achieving full knee ROM.

She returned 08-31-04, approximately six weeks postoperatively, and she rated her knee at 60% and had returned to all normal activities of daily living including helping out on the family farm. She continued to perform the prescribed exercises four times per day. Her ROM on the right involved knee was 10-0-143° versus 10-0-150° in the left normal knee. She was able to sit on her heels but had an uncomfortable tilt. Her knee had a mild effusion and she had a normal gait, no tenderness, and an active heel lift that was not yet equal to the opposite normal knee. She was instructed to continue with her previous home exercise program but she could gradually decrease using the extension device to 1-2 times per day as long as she did not lose extension. Upon achieving full ROM symmetrically equal to the opposite knee, she was able to begin biking and elliptical cross trainer, single-leg press, single-leg extensions, and step down exercises. These exercises were performed one time per day, 3 - 5 times per week. Progression of the low-impact and strengthening program was allowed as long as no ROM was lost or compromised.

Figure 6: Sitting on Heels: Equal knee flexion can be demonstrated by having the patient sit on his/her heels comfortably and symmetrically.

On 09-23-04, approximately two months after her surgery, she underwent isokinetic strength testing at 180° and 60° speeds and single-leg hop testing.[21] These strength tests were repeated at four, six, and eight months postoperatively. At four months she was allowed to begin shooting baskets and light agility drills. At eight months postoperatively she was released to full participation *(Table 3)*.

OUTCOMES

At four months postoperatively, the patient had symmetrical knee ROM including full equal hyperextension and full equal flexion. She had an equal active heel lift and was able to sit on her heels equally and comfortably. Isokinetic strength testing of the involved knee compared with the opposite normal knee revealed 79% strength at 180°/s speed and 66% strength at 60°/s speed. She rated her knee at 80%.

At one year postoperatively, the patient's knee had symmetrical ROM including full equal hyperextension and full equal flexion. She had an equal active heel lift and

Table 3. Order of events using knee extension device.

EVENT	DATE	Right Knee ROM	STRENGTH 180°	STRENGTH 60°	ACTIVITY
Initial Evaluation	05-25-04	0-10-110°			
2 weeks	06-09-04	5-0-110°			
4 weeks	07-06-04	5-0-110°			
Arthroscopic scar resection	07-19-04				
Hospital Discharge	07-20-04	10-0-90°			Bed rest x 3 days
3 days PO	07-23-04	10-0-115°			
10 days PO	08-03-04	10-0-125°			
6 wks PO	08-31-04	10-0-143°			Low impact
2 mos PO	09-23-04	10-0-148°			
4 mos PO	11-16-04	10-0-150°	79%	66%	Shooting baskets
6 mos PO	01-12-05	10-0-150°	74%	75%	Agility drills
8 mos PO	03-09-05	10-0-150°	95%	83%	Return to basketball
1 yr PO	07-19-05	10-0-150°	89%	96%	

PO = postoperatively

was able to sit on her heels equally and comfortably. Her quadriceps muscle strength was 89% of the opposite normal knee at 180°/s speed and 96% strength at 60°/s speed with isokinetic strength testing. She tested 101% on the single-leg-hop test. She rated her knee at 98% and her knee had a mild effusion. The patient's IKDC score at one year postoperatively was 97/100, more than doubling the score she achieved on her initial visit. Additionally the patient returned to full athletic competition without pain or difficulty and was formally discharged from physical therapy at that time.

DISCUSSION

The treatment of arthrofibrosis is often a costly and time intensive treatment process. The focus of treatment in most published articles is in regards to surgical intervention with varying rehabilitation protocols. Authors of previously published papers state the importance of acquiring extension but no consensus exists on the best way to achieve this movement.[2-4,8,11,22] Some authors have tried extension casts which require multiple visits to the clinic and can be very uncomfortable. In addition, a cast prevents the patient from being able to perform exercises in between visits. The use of the extension device used with the patient in this report allowed for a patient controlled intervention in increasing knee extension to include hyperextension.

Although most authors agree that restoration of normal knee ROM is a key tenant of treatment, disagreement exists as to what constitutes "normal" ROM. Other treatment programs to regain knee extension fail to take into account that most people have some degree of knee hyperextension. Many authors report they had achieved good ROM results by achieving zero degrees, however, these authors still did not have a good outcome.[1,5-7,9,22] Achieving full hyperextension equal to the opposite normal knee was the focus of this rehabilitation utilizing the knee extension device. Previous attempts in physical therapy that utilized therapeutic exercises and manual therapy had failed. In this case report, full ROM equal to the opposite normal knee was achieved and it is the author's opinion that this achievement of full extension was the most important factor in returning the patient to an active lifestyle, including competitive basketball.

Maximizing extension preoperatively may have helped in obtaining full extension postoperatively. Avoiding a hemarthrosis and subsequent quadriceps inhibition after surgery allowed for early quadriceps activation and the ability to maintain full terminal knee extension. Once the patient was able to maintain extension, flexion exercises were initiated followed by the rehabilitation program described earlier.

CONCLUSION

While prevention provides the best treatment for arthrofibrosis, a need exists for data on the best way to treat arthrofibrosis once it has occurred. This case is an example of a successful outcome in the treatment of Type 3 arthrofibrosis in which a knee extension device was utilized. The rehabilitation program described in this case study may assist physical therapists and physicians in the treatment of patients with arthrofibrosis.

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INVITED CLINICAL COMMENTARY

PRE-PARTICIPATION SCREENING: THE USE OF FUNDAMENTAL MOVEMENTS AS AN ASSESSMENT OF FUNCTION – PART 2

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ABSTRACT

Part I of this two-part series (presented in the May issue of *NAJSPT)* provided the background, rationale, and a complete reference list for the use of fundamental movements as an assessment of function during pre-participation screening. In addition, Part I introduced one such evaluation tool that attempts to assess the fundamental movement patterns of an individual, the Functional Movement Screen (FMS)™, and described three of the seven fundamental movement patterns that comprise the FMS™.

Part II of this series provides a brief review of the analysis of fundamental movement as an assessment of function. In addition, four additional fundamental tests of the FMS™, which complement those described in Part I, will be presented (to complete the total of seven fundamental tests): shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. These four patterns are described in detail, a grading system from 0-III is defined for each pattern, and the clinical implications for receiving a grade less than a perfect III are proposed.

By reading Part I and Part II, it is hoped that the clinician will recognize the need for the assessment of fundamental movements, critique current and develop new methods of functional assessment, and begin to provide evidence related to the assessment of fundamental movements and the ability to predict and reduce injury. By using such a screening system, the void between pre-participation screening and performance tests will begin to close.

Key Words: pre-participation screening, performance tests, function

INTRODUCTION

The assessment of fundamental movements is an attempt to pinpoint deficient areas of mobility and stability that may be overlooked in the asymptomatic active population. The ability to predict injuries is equally as important as the ability to evaluate and treat injuries. The difficulty in preventing injury seems to be directly related to the inability to consistently determine those athletes who are predisposed to injuries. In many situations, no way exists for knowing if an individual will fall into the injury or non-injury category – no matter what the individual's risk factors are. Meeuwisse[1] suggested that unless specific markers are identified for each individual, determining who is predisposed to injuries would be very difficult.

The inconsistencies surrounding the pre-participation physical and performance tests offer very little assistance in identifying individuals who are predisposed to injuries. These two evaluation methods do not offer predictable and functional tests that are individualized and may assist in identifying specific kinetic chain weaknesses. Numerous sports medicine professionals have suggested the need for specific assessment techniques that utilize a more functional approach in order to identify movement deficits.[2-4]

The Functional Movement System (FMS)™ is an attempt to capture movement pattern quality with a primitive grading system that begins the process of functional movement pattern assessment in normal individuals. It is not intended to be used for diagnosis, but rather to demonstrate limitations or

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asymmetries with respect to human movement patterns and eventually correlate these limitations with outcomes, which may lead to an improved proactive approach to injury prevention.[5]

The FMS™ may be included in the pre-placement/ pre-participation physical examination or be used as a stand-alone assessment technique to determine deficits that may be overlooked during the traditional medical and performance evaluations. In many cases, muscle flexibility and strength imbalances may not be identified during the traditional assessment methods. These problems, previously acknowledged as significant risk factors, can be identified using the FMS™. This movement-based assessment serves to pinpoint functional deficits (or biomarkers) related to proprioceptive, mobility and stability weaknesses.

Scoring the Functional Movement Screen™

The scoring for FMS™ was provided in detail in Part I. The exact same instructions for scoring each test are repeated here to allow the reader to score the additional tests presented in Part II without having to refer to Part 1. The scores on the FMS™ range from zero to three; three being the best possible score. The four basic scores are quite simple in philosophy. An individual is given a score of zero if at any time during the testing he/she has pain anywhere in the body. If pain occurs, a score of zero is given and the painful area is noted. A score of one is given if the person is unable to complete the movement pattern or is unable to assume the position to perform the movement. A score of two is given if the person is able to complete the movement but must compensate in some way to perform the fundamental movement. A score of three is given if the person performs the movement correctly without any compensation. Specific comments should be noted defining why a score of three was not obtained.

The majority of the tests in the FMS™ test right and left sides respectively, and it is important that both sides are scored. The lower score of the two sides is recorded and is counted toward the total; however it is important to note imbalances that are present between right and left sides.

Three tests have additional clearing screens which are graded as positive or negative. These clearing movements only consider pain, if a person has pain then that portion of the test is scored positive and if there is no pain then it is scored negative. The clearing tests affect the total score for the particular tests in which they are used. If a person has a positive clearing screen test then the score will be zero.

All scores for the right and left sides, and those for the tests which are associated with the clearing screens, should be recorded. By documenting all the scores, even if they are zeros, the sports rehabilitation professional will have a better understanding of the impairments identified when performing an evaluation. It is important to note that only the lowest score is recorded and considered when tallying the total score. The best total score that can be attained on the FMS™ is twenty-one.

DESCRIPTION OF THE FMS™ TESTS

The following are descriptions of the final four specific tests used in the FMS™ and their scoring system. Each test is followed by tips for testing developed by the authors as well as clinical implications related to the findings of the test.

Shoulder Mobility

Purpose. The shoulder mobility screen assesses bilateral shoulder range of motion, combining internal rotation with adduction and external rotation with abduction. The test also requires normal scapular mobility and thoracic spine extension.

Description. The tester first determines the hand length by measuring the distance from the distal wrist crease to the tip of the third digit in inches. The individual is then instructed to make a fist with each hand, placing the thumb inside the fist. They are then asked to assume a maximally adducted, extended, and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other. During the test the hands should remain in a fist and they should be placed on the back in one smooth motion. The tester then measures the distance between the two closest bony prominences. Perform the shoulder mobility test as many as three times bilaterally *(Figures 1-3)*.

Tips for Testing:

- The flexed shoulder identifies the side being scored
- If the hand measurement is exactly the same as the distance between the two points then score the subject low
- The clearing test overrides the score on the rest of the test
- Make sure individual does not try to "walk" the hands toward each other

Figure 1. ***Shoulder Mobility III***

Figure 2 ***Shoulder Mobility II***

Figure 3. ***Shoulder Mobility I***

III

- Fists are within one hand length (Assume one hand length is 8 inches)

II

- Fists are within one and a half hand lengths (Assume one and one half hand lengths is 12 inches)

I

- Fists are not within one and half hand lengths (Beyond 12 inches)

Clearing exam. A clearing exam should be performed at the end of the shoulder mobility test. This movement is not scored it is simply performed to observe a pain response. If pain is produced, a score of zero is given to the entire shoulder mobility test. This clearing exam is necessary because shoulder impingement can sometimes go undetected by shoulder mobility testing alone.

The individual places his/her hand on the opposite shoulder and then attempts to point the elbow upward *(Figure 4)*. If there is pain associated with this movement, a score of zero is given. It is recommended that a thorough evaluation of the shoulder be done. This screen should be performed bilaterally.

Figure 4. ***Shoulder Clearing Test***

Clinical Implications for Shoulder Mobility

The ability to perform the shoulder mobility test requires shoulder mobility in a combination of motions including abduction/external rotation, flexion/extension, and adduction/internal rotation. This test also requires scapular and thoracic spine mobility.

Poor performance during this test can be the result of several causes, one of which is the widely accepted explanation that increased external rotation is gained at the expense of internal rotation in overhead throwing athletes. In addition, excessive development and shortening of the pectoralis minor or latissimus dorsi muscles can cause postural alterations of forward or rounded shoulders. Finally, a scapulothoracic dysfunction may be present, resulting in decreased glenohumeral mobility secondary to poor scapulothoracic mobility or stability.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements of the joints as well as muscular flexibility tests such as Kendall's[6] test for pectoralis minor and latissimus dorsi tightness or Sahrmann's[7] tests for shoulder rotator tightness.

Previous testing has identified that when an athlete achieves a score of II, minor postural changes or shortening of isolated axio-humeral or scapulo-humeral muscles exist. When an athlete scores a I or less, a scapulothoracic dysfunction may exist.

Active Straight Leg Raise

Purpose. The active straight leg raise tests the ability to dis-associate the lower extremity from the trunk while maintaining stability in the torso. The active straight leg raise test assesses active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis and active extension of the opposite leg.

Description. The individual first assumes the starting position by lying supine with the arms in an anatomical position and head flat on the floor. The tester then identifies mid-point between the anterior superior iliac spine (ASIS) and mid-point of the patella, a dowel is then placed at this position perpendicular to the ground. Next, the individual is instructed to lift the test leg with a dorsi-flexed ankle and an extended knee. During the test the opposite knee should remain in contact with the ground, the toes should remain pointed upward, and the head remain flat on the floor. Once the end range position is achieved, and the malleolus is located past the dowel then the score is recorded per the established criteria (explained later). If the malleolus does not pass the dowel then the dowel is aligned along the medial malleolus of the test leg, perpendicular to the floor and scored per the established criteria. The active straight leg raise test should be performed as many as three times bilaterally *(Figures 5-7).*

Tips for Testing:

- The flexed hip identifies the side being scored
- Make sure leg on floor does not externally rotate at the hip
- Both knees remain extended and the knee on the extended hip remains touching the ground
- If the dowel resides at exactly the mid-point, score low

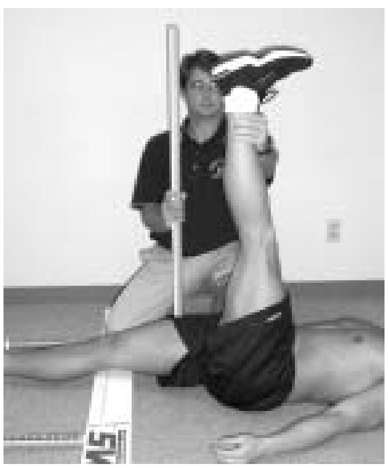

Figure 5. ***Active SLR III***

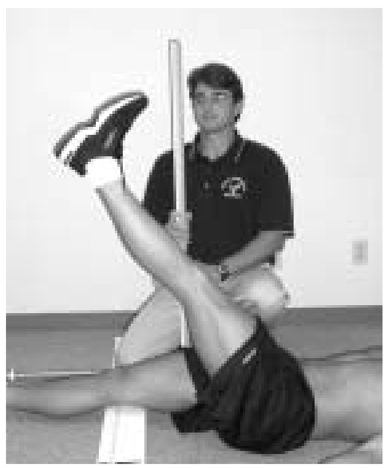

Figure 6. ***Active SLR II***

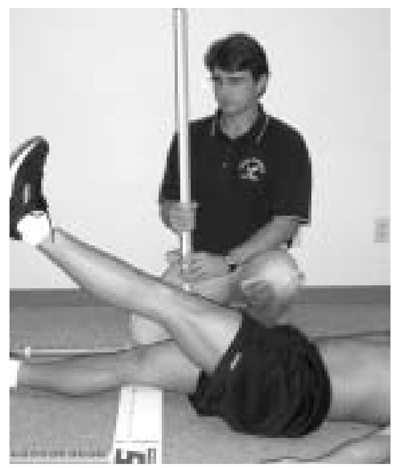

Figure 7. ***Active SLR I***

III
- Ankle/Dowel resides between mid-thigh and ASIS

II
- Ankle/Dowel resides between mid-thigh and mid-patella/joint line

I
- Ankle/Dowel resides below mid-patella/joint line

Clinical Implications for Active Straight Leg Raise

The ability to perform the active straight leg raise test requires functional hamstring flexibility, which is the flexibility that is available during training and competition. This is different from passive flexibility, which is more commonly assessed. The athlete is also required to demonstrate adequate hip mobility of the opposite leg as well as lower abdominal stability.

Poor performance during this test can be the result of several factors. First, the athlete may have poor functional hamstring flexibility. Second, the athlete may have inadequate mobility of the opposite hip, stemming from iliopsoas inflexibility associated with an anteriorly tilted pelvis. If this limitation is gross, true active hamstring flexibility will not be realized. A combination of these factors will demonstrate an athlete's relative bilateral, asymmetric hip mobility. Like the hurdle step test, the active straight leg raise test reveals relative hip mobility; however, this test is more specific to the limitations imposed by the muscles of the hamstrings and the iliopsoas.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by Kendall's sit-and-reach test as well as the 90-90 straight leg raise test for hamstring flexibility. The Thomas test can be used to identify iliopsoas flexibility.[6]

Previous testing has identified that when an athlete achieves a score of II, minor asymmetric hip mobility limitations or moderate isolated, unilateral muscle tightness may exist. When an athlete scores a I or less, relative hip mobility limitations are gross.

Trunk Stability Push-Up

Purpose. The trunk stability push-up tests the ability to stabilize the spine in an anterior and posterior plane during a closed-chain upper body movement. The test asseses trunk stability in the sagittal plane while a symmetrical upper-extremity motion is performed.

Description. The individual assumes a prone position with the feet together. The hands are then placed shoulder width apart at the appropriate position per the criteria described later. The knees are then fully extended and the ankles are dorsiflexed. The individual is asked to perform one push-up in this position. The body should be lifted as a unit; no "lag" should occur in the lumbar spine when performing this push-up. If the individual cannot perform a push-up in this position, the hands are lowered to the appropriate position per the established criteria *(Figures 8-10)*.

Tips for Testing:
• Tell them to lift the body as a unit
• Make sure original hand position is maintained and the hands do not slide down when they prepare to lift
• Make sure their chest and stomach come off the floor at the same instance
• When in doubt score it low
• The clearing test overrides the test score

Figure 8. ***Trunk Stab Push Up III (male)***

III

• Males perform one repetition with thumbs aligned with the top of the forehead
• Females perform one repetition with thumbs aligned with chin

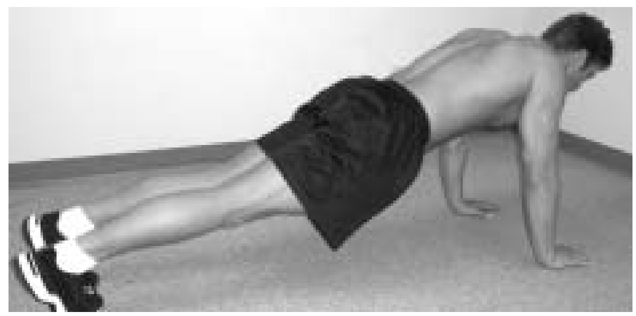

Figure 9. ***Trunk Stab Push Up II (male)***

II

• Males perform one repetition with thumbs aligned with chin
• Females perform one repetition with thumbs aligned with clavicle

Figure 10. ***Trunk Stab Push Up II (male)***

I

• Males are unable to perform one repetition with hands aligned with chin
• Females are unable to perform one repetition with thumbs aligned with clavicle

Clearing exam. A clearing exam is performed at the end of the trunk stability push-up test. This movement is not scored; the test is simply performed to observe a pain response. If pain is produced, a score of zero is given for the entire push-up test. This clearing exam is necessary because back pain can sometimes go undetected during movement screening.

Spinal extension can be cleared by performing a press-up in the push-up position *(Figure 11)*. If pain is associated with this motion, a zero is given and a more thorough evaluation should be performed.

Figure 11. ***Spinal Extension Clearing Test***

Clinical Implications for Trunk Stability Push-up

The ability to perform the trunk stability push-up requires symmetric trunk stability in the sagittal plane during a symmetric upper extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force symmetrically from the upper extremities to the lower extremities and vice versa. Movements such as rebounding in basketball, overhead blocking in volleyball, or pass blocking in football are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed and lead to poor functional performance, as well as increased potential for micro traumatic injury.

Poor performance during this test can be attributed simply to poor stability of the trunk stabilizers. When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using test by Kendall[6] or Richardson et al[8] for upper and lower abdominal and trunk strength. However, the test by Kendall[6] requires a concentric contraction while a push-up requires an isometric stabilizing reaction to avoid spinal hyperextension. A stabilizing contraction of the core musculature is more fundamental and appropriate than a simple strength test, which may isolate one or two key muscles. At this point, the muscular deficit should not necessarily be diagnosed. The screening exam simply implies poor trunk stability in the presence of a trunk extension force, and further examination at a later time is needed to formulate a diagnosis..

Rotary Stability

Purpose. The rotary stability test is a complex movement requiring proper neuromuscular coordination and energy transfer from one segment of the body to another through the torso. The rotary stability test assesses multi-plane trunk stability during a combined upper and lower extremity motion.

Description. The individual assumes the starting position in quadruped with their shoulders and hips at 90 degrees relative to the torso. The knees are positioned at 90 degrees and the ankles should remain dorsiflexed. The individual then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately 6 inches. The same shoulder is then extended and the knee flexed enough for the elbow and knee to touch. This is performed bilaterally for up to three repetitions. If a III is not attained then the individual performs a diagonal pattern using the opposite shoulder and hip in the same manner as described *(Figures 12-16)*.

Tips for Testing:

• Scoring is identified by the upper extremity movement on the score sheet, but even if someone gets a three, both diagonal patterns must be performed and scored. The information should be noted
• Make sure the elbow and knee touch during the flexion part of the movement
• Provide cueing to let the individual know that he/she does not need to raise the hip and arm above 6 inches off of the floor
• When in doubt, score the subject low
• Do not try to interpret the score when testing

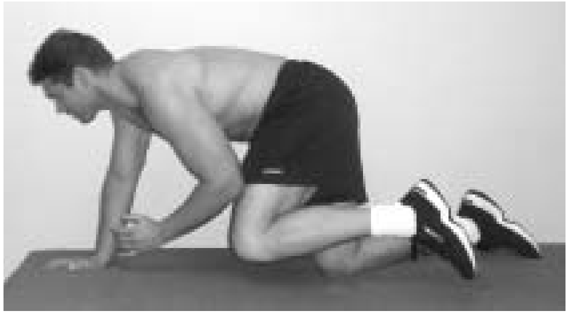

Figure 12. ***Rotary Stab Start III***

Figure 13. ***Rotary Stab Finish III***

III

- Performs one correct unilateral repetition while keeping spine parallel to surface
- Knee and elbow touch

Figure 14. ***Rotary Stab Start II***

Figure 15. ***Rotary Stab Finish II***

II

- Performs one correct diagonal repetition while keeping spine parallel to surface
- Knee and elbow touch

Figure 16. ***Rotary Stab Start I***

I

- Inability to perform diagonal repetitions

Clearing exam. A clearing exam is performed at the end of the rotary stability test. This movement is not scored it is simply performed to observe a pain response. If pain is produced, a score of zero is given to the entire rotary stability test. This clearing exam is necessary because back pain can sometimes go undetected by movement screening.

Spinal flexion can be cleared by first assuming a quadruped position and then rocking back and touching the buttocks to the heels and the chest to the thighs *(Figure 17)*. The hands should remain in front of the body reaching out as far as possible.

Figure 17. ***Spinal Flexion Clearing Test***

Clinical Implications for Rotary Stability

The ability to perform the rotary stability test requires asymmetric trunk stability in both sagittal and transverse planes during asymmetric upper and lower extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force asymmetrically from the lower extremities to the upper extremities and vice versa. Running and exploding out of a down stance in football and track are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed, leading to poor performance and increased potential for injury.

Poor performance during this test can be attributed simply to poor asymmetric stability of the trunk stabilizers. When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using Kendall's test for upper and lower abdominal strength.[6]

SUMMARY

The research related to movement-based assessments is extremely limited, mainly because only a few movement-based quantitative assessment tests are being utilized. According to Battie et al,[4] the ultimate test of any pre-employment or pre-placement screening technique is its effectiveness in identifying individuals at the highest risk of injury. If the FMS™, or any similarly developed test, can identify at risk individuals, then prevention strategies can be instituted based on their scores. A proactive, functional training approach that decreases injury through improved performance efficiency will enhance overall wellness and productivity in many active populations.

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The Functional Movement Screen™ is the registered trademark of FunctionalMovement.com with profits from the sale of these products going to Gray Cook and Lee Burton. The Editors of NAJSPT emphasize (and the authors concur) that the use of fundamental movements as an assessment of function is the important concept to be taken from Part I and Part II of this series and can be performed without the use of the trademarked equipment.

EDITORIAL

WANTED: A FEW GOOD AUTHORS!

Barbara Hoogenboom, PT, EdD, SCS, ATC[a]
Michael Voight, PT, DHSc, OCS, SCS, ATC[b]

Contrary to the title of this editorial—which is supposed to get your attention—we will accept *all* good authors. The demand for clinically relevant evidence in the profession of physical therapy has never been greater. Knowledgeable, intelligent, and evolving professionals, clinicians, educators, and students are continually seeking to advance their skills, justify treatment choices, and improve patient outcomes based on the available evidence. The *North American Journal of Sports Physical Therapy* (*NAJSPT*) is a peer-reviewed journal that reviews manuscripts that relate to all aspects of sports physical therapy for possible publication. *NAJSPT* publishes relevant, timely, and interesting papers that add to the existing evidence related to the practice of sports physical therapy. This editorial seeks to motivate and prepare the new or would-be author to go to the keyboard, and start writing!

Writing for publication in a peer-reviewed journal often appears a daunting process, one that is foreign to most clinicians and many beginning academicians. Scientific writing takes time above and beyond your regular work commitments. Few clinics or academic institutions provide time for writing! In addition to being costly in terms of time investment, scientific writing for publication is a venture fraught with possible pitfalls and rejection, so many excellent scholars and clinicians avoid it. To quote Jeffers,[1] as quoted by Foreman[2] in a similar editorial written in 2005, "Feel the fear and do it anyway!"

Many of you are experts in your area of practice. Many of you have ideas and thoughts to share. Many others conduct important clinical research in the context of your clinics. We would like to encourage *you* (any and all of *you* who spend time reading this editorial) to consider contributing to the evidence in sports physical therapy via the vehicle known as *NAJSPT*. We believe that many authors exist who have just not yet begun writing.

Begin the process with a topic in which you have interest. Perhaps with a clinical technique, research conducted in your clinic, a controversial protocol, or that Masters' thesis or Doctoral dissertation that the world should know about....an idea is all that it takes!

Next, choose a type of paper you are going to write. *NAJSPT* provides a wide variety of outlets for your dissemination. Manuscripts submitted to the *NAJSPT* are reviewed under one of the following categories: Original Research Contribution, Review of Literature (Qualitative or Systematic), Clinical Commentary, Case Report, and Clinical Suggestion. Please review the pages at the end of the journal (and at the end of every journal) to see what is required for submission in each category.

Manuscript preparation: The writing phase. Remember that the best writing is preceded by planning. By knowing the guidelines for *NAJSPT* in the back of each journal, you can choose a type of paper and tailor your writing and citations accordingly. When writing, one of the hardest things to do is get started. We suggest that you write when you have a block of time with no distractions to dedicate to the project. (Kids and family commitments, laundry and household chores, email, and sports on TV always work to distract the authors of this editorial.)

When writing, we have found that saving the work often prevents frustrating losses of text that happen at the least opportune times. When ready, share your draft with a trusted colleague who can critique your work and suggest changes or help you clarify your writing. We find that what is "clear" to the original author may not be so clear to another reader, so this process of sharing and clar-

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ification is helpful prior to submission. Our suggestion is to take 1-2 days to digest your trusted colleague's advice before responding. Criticism may be tough in the short run, but in the long run, it will improve your manuscript. Remember to ask one question: Is the submission better? In most cases, the feedback makes for a better submission to a journal.

Also remember to cite frequently and make sure that your citations comply with the AMA style required by the *NAJSPT*. Abbreviations for journals should reflect the current practice as set by Index Medicus. We find that the use of a reference manager will help you avoid renumbering or redoing references in the event that an additional reference must be added when the manuscript is complete.

Be sure to get written permission from any clinic or persons that you use in photographs. If you use figures, diagrams, or artwork from other sources, seek permission to have copyright release prior to publication.

Submission of your article. Most journals have a set format in which to submit manuscripts and any tables, figures, or pictures. The preferred method for the *NAJSPT* is electronic; however, authors can also put forward a paper submission. A copy of the manuscript on CD should accompany the paper submission.

The review and editorial process. All manuscripts submitted are peer-reviewed in a blind process by at least two members of the *NAJSPT* Editorial Board — who provide a recommendation for acceptance, revision, or rejection to one of the Associate Editors. The Associate Editor then summarizes the reviews and sends a recommendation to the Editor-in-Chief. The final decision concerning the publication of a manuscript is solely the responsibility of the Editor-in-Chief. Rarely does the review process result in a complete rejection of the manuscript with no feedback. Rather, the review should be seen as a form of peer feedback with assistance and comments that may make the manuscript more clear to the end reader or strengthen the results. As members of the editorial staff of *NAJSPT*, we will say that feedback from those who have undergone the review process is overwhelmingly positive, and the people submitting usually thank us even when the manuscript is rejected. To date, the *NAJSPT* has an acceptance rate approaching 70% with a submission to decision time of approximately four months.

Conclusion. We sincerely hope that this review of instructions to authors and considerations for writing contained in this editorial will help you get started on the writing track! The utility, clinical relevance, and timeliness of information to be shared with the sports rehabilitation community is up to *you*. You are the writers that will fill the pages of *NAJSPT*, the journal of which the Sports Physical Therapy Association is so proud. We hope that these thoughts and ideas inspire you to get off the fence and write!

Barbara J. Hoogenboom, PT, EdD, SCS, ATC
Michael L. Voight, PT, DHSc, OCS, SCS, ATC

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ORIGINAL RESEARCH

REHABILITATION OF PATIENTS FOLLOWING AUTOGENIC BONE-PATELLAR TENDON-BONE ACL RECONSTRUCTION: A 20-YEAR PERSPECTIVE

Mark S. De Carlo, PT, MHA, SCS, ATC[a]
Ryan McDivitt, DPT, ATC[a]

ABSTRACT

Rehabilitation of patients following anterior cruciate ligament (ACL) reconstruction has undergone remarkable improvements over the past two decades. During this time, ACL research has been at the forefront of many orthopaedic and sports physical therapy clinics. With over 20 years of ACL rehabilitation experience (senior author) and prior collaboration with accelerated ACL rehabilitation pioneer K. Donald Shelbourne, the authors wish to present a unique perspective on the evolution of ACL rehabilitation.

Prior to the classic article by Paulos et al in 1981,[1] literature on ACL rehabilitation was quite sparse. The basis for ACL rehabilitation at this time was founded in basic science studies conducted with animal models. In an effort to protect the graft, emphasis was placed on immobilization, extension limitation, restricted weight bearing, and delayed return to activity. Despite achieving good ligamentous stability, patients often experienced a spectrum of complications.

In 1990, Shelbourne and Nitz[2] proposed an accelerated rehabilitation protocol following ACL reconstruction based on clinical experience. Their program emphasized delayed surgery, earlier range of motion and weight bearing, and full extension. As a result, patients experienced better clinical outcomes while maintaining knee stability.

The rehabilitation program presented in this paper is still largely based on the principles of the accelerated protocol. As evidence-based practice and the call for prospective, randomized clinical research continues, the continued progress in treating patients with this injury will be enhanced. Furthermore, clinicians are urged not to lose sight of the clinical reasoning that helped evolve the ACL rehabilitation process where it is today.

Key words: anterior cruciate ligament, knee, postoperative, evidence-based practice.

INTRODUCTION

Rehabilitation of patients following anterior cruciate ligament (ACL) reconstruction has undergone remarkable improvements over the past two decades. In 1983, one author reported on "The Anterior Cruciate Ligament Problem," indicating no ideal treatment for a patient with ACL disruption existed.[3] Initial surgical treatment of ACL injuries resulted in a high incidence of complications, which led many authors to favor nonoperative treatment and conservative rehabilitation.[3] As surgical techniques improved and surgical outcomes became more predictable, postoperative rehabilitation became the key variable in determining successful outcomes.

Prior to the classic article by Paulos et al,[1] literature regarding ACL rehabilitation was scarce. Initial reports of rehabilitation of patients following ACL reconstruction consisted of a few general paragraphs at the end of an article regarding surgical procedures. From 1980 to 1985, ACL literature increased dramatically as the period produced more articles than the previous 80 years.[4] Since this time, ACL research has been at the forefront of many orthopaedic and sports physical therapy clinics.

With over 20 years of ACL rehabilitation experience (senior author) and prior collaboration with accelerated ACL rehabilitation pioneer, K. D. Shelbourne MD, the authors wish to present a unique perspective on the evolution of ACL rehabilitation. The term

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accelerated rehabilitation will be used for the context of this paper to refer to the concept of a rehabilitation progression designed to allow early, yet safe return to activities following ACL reconstruction. The term traditional rehabilitaion will be used to describe the more conservative, time-based, protocols that were commonly used in the past. This commentary will provide a brief history of the basic science models that led to the traditional rehabilitation protocols, highlight rehabilitation models proposed by Paulos et al[1] and Shelbourne and Nitz,[2] provide evidence for the principles behind the accelerated rehabilitation program following ACL reconstruction, and re-emphasize key points to successful rehabilitation outcomes following ACL reconstruction. Although the impact of surgical technique and graft selection on the rehabilitation process is important, such topics are beyond the scope of this paper.

BASIC SCIENCE MODELS

During the 1970's, basic science studies conducted with animal models provided the framework for the traditional rehabilitation model. This data was extrapolated and applied to humans. Application of animal studies should be done with caution due to the differences between the species. Many authors openly stated this limited applicability to clinical human cases.[1,5,6] However, clinicians acted on the best available evidence at the time.

Great uncertainty existed as to the role of the ACL in knee joint stability and the long-term effects of knee instability.[7] A classic study by Marshall and Olsson[8] transected the ACL in 10 dogs and two dogs were used as a control group. The dogs were followed for up to 23 months. Macroscopic, histological, and microroentgenographic examinations revealed osteophytes progressively increasing in size for up to one year as well as proliferative and degenerative changes in the articular tissues. A close relationship existed between instability evaluated by an anterior drawer test and articular changes. The authors concluded that early stabilization was indicated in cases of ACL rupture. A biomechanical study by Butler et al[9] sought to determine the importance of knee ligaments in resisting joint translation. They used 14 human cadaver knees secured to a load cell and moving actuator to measure the restraining forces against the anterior and posterior drawer tests. Ligaments were sectioned individually and the test repeated to determine the contribution to restraint. Test result indicated that the ACL provided up to 86% of restraint against anterior translation in the knee. As the function of the ACL and the need for stabilization became clearer, the number and type of surgical procedures increased.[4]

Following ACL disruption and reconstruction or repair, immobilization for an extended period of time was the standard form of treatment. Noyes and colleagues[5,10] reported the functional properties of ligaments in monkeys. Wild primates were immobilized for eight weeks in total body plaster prior to undergoing mechanical testing in tension to failure under high strain-rate conditions. The results of testing on 100 knee specimens showed a significant decrease in ligament strength and stiffness following 8-weeks of immobilization. Two subgroups of monkeys underwent 5 and 12 month reconditioning periods prior to testing. Results showed incomplete recovery of ligament properties 5 months after resumed activity and strength properties required up to 12 months to return to normal. As a result, they suggested delayed return to activity for an extended period of time following immobility, delayed return to strenuous activity for 6 to 12 months, and prescribed protective measures during rehabilitation. The application to humans suggested an extended delay for return to activity rather than shortening the length of immobilization.

The vascular anatomy and healing process of the ACL were described in dogs. Arnoczky et al[11] utilized microangiography, histology, and tissue-clearing techniques to analyze the normal vascular anatomy in eight dogs. They reported that the central portion of a normal canine ACL had decreased vascularity. Eight weeks following complete ACL transaction, spontaneous healing had not occurred in one animal. Alm et al[12] studied the revascularization process following ACL reconstruction in 29 dogs. Through microangiography and histological study, they found that the original vascularization of the distal and middle portionss of the patellar tendon graft were preserved. The proximal and middle parts of the graft where the suture was attached were initially devoid of functioning vessels and had revascularized by 2 months. The structure of the graft resembled a normal ligament at 4 to 5 months.

Clancy and coworkers[13] studied the vascularity of the patellar tendon graft in monkeys at 2, 3, 6, 9, and 12 months following ACL reconstruction. Microangiographic and histologic examinations were performed on one animal at each of the follow-up periods. They found that patellar tendon grafts in monkeys were revascularized after 8 weeks and resembled a normal ligament at 9 months and 12 months. Arnoczky et al[14] studied the revascularization pattern of patellar tendon grafts in dogs at 2, 4, 6, 8, 10, 16, 20, 26, and 52 weeks postoperatively. Four animals underwent histological and tissue-clearing techniques at each of the follow-up periods. The authors described the graft undergoing phases of ischemic necrosis, revascularization, proliferation, and remodeling. The transplanted graft had intrinsic vessels by 8 weeks, was completely vascularized by 20 weeks, and had the histological appearance of a normal ligament at one year. Amiel et al[15] studied the morphology of patellar tendon grafts in rabbits at 2, 3, 4, 6, and 30 weeks following ACL reconstruction. Histological and biochemical examination were performed on five animals at each of the follow-up periods. The grafts demonstrated a gradual assumption of the microscopic properties of the normal ACL. By 30 weeks postoperatively, collagen concentrations of the graft were the same as the normal ACL and cell morphology appeared ligamentous. The authors referred to this gradual process as "ligamentization." The common theme during this time period was that vascularization of a transplanted graft required 8 weeks and ligamentization required up to one year.

Rougraff et al[16] performed arthroscopic and histologic analysis of patellar tendon autografts following ACL reconstruction. The knees of 23 patients underwent arthroscopy and biopsy from 3 weeks to 6.5 years postoperatively. They observed that human patellar tendon autografts were viable as early as 3 weeks with exception of the central biopsy at 3 weeks. They detected increased neovascularity, nuclear morphology, and fibroblastic activity in the human grafts as compared to the necrotic stage observed in animals. Ligamentization required up to 3 years to complete.

To determine the strength of an ACL substitute, researchers studied the mechanical properties of various graft sources. Clancy et al[13] studied the tensile strength of patellar tendon grafts in monkeys at 3, 6, 9, and 12 months postoperatively. Three animals at the first three follow-up periods and five animals at the final follow-up period underwent stress to failure testing. The results demonstrated patellar tendon grafts had regained 81% of their original tensile strength prior to transfer at 9 and 12 months following reconstruction and were 52% of the strength of the normal ACL at 12 months following reconstruction. The authors considered these results significant because Butler et al[17] had demonstrated that a third of the patellar tendon in humans had 191% of the strength of the ACL. Noyes et al[18] compared the mechanical properties of nine human ligament graft tissues obtained from young trauma victims (mean age 26 years). The tissues studied included the ACL, central and medial portions of the bone-patellar tendon-bone (BPTB), semitendinosis, fascia lata, gracilis, distal iliotibial tract, and the medial, central, and lateral portions of the quadriceps tendon-patellar retinaculum-patellar tendon. All tissues were subjected to high-strain-rate failure tests to determine strength and elongation properties. The BPTB graft was the strongest with a mean strength of 159% to 168% of that of an ACL. The strength of the substitute graft would theoretically affect the initiation of motion and strengthening activities during the rehabilitation process.

Controversy surrounded the safety of simple motion and other stresses as researchers attempted to identify strain imposed on the ACL during rehabilitation. Grood et al[19] studied the biomechanics of knee extension and the effect of cutting the ACL in human cadavers. They reported increased anterior tibial translation during knee extension from 30° of flexion to full extension. Arms and colleagues[20] studied ACL strain during knee ROM and simulated quadriceps contractions in human cadavers. Using a strain transducer, they showed that ACL strain decreased as the knee was passively flexed from 0° until 30°-35° where the ACL underwent minimal strain. Further flexion increased the strain to a maximum at 120 degrees. Isometric and eccentric quadriceps contractions significantly increased ACL strain through the first 45° of knee flexion while isometric contraction at flexion angles greater than 60° decreased ACL strain. Quadriceps activity beyond 60° was determined to be safe. The authors speculated that immobilization might not protect the graft if isometric quadriceps contractions occur. Henning et al[21] used an in vivo strain gauge to study the load-elongation of the ACL during rehabilitation exercises. Two subjects with acute grade II ACL sprains were utilized and the results were scaled to an 80-pound Lachman test. Cycling produced 7%, single leg half squat produced 21%, normal walking produced 36%, quadriceps contraction against 20 pounds of resistance at 45° produced 50% and at terminal extension produced 121%, and downhill running produced 125% as much elongation as an 80 pound Lachman test. The authors recommended that knee extension not be performed through a full ROM during the first year following ACL reconstruction. Strain data gave clinical insight to the stress produced on the ACL during various rehabilitation activities. Clinicians used this information to avoid certain exercises and thus protect the healing ACL.

However, there are no direct methods of knowing the limits of strain that are safe for a healing ligament or graft.

Rougraff and Shelbourne[22] suggested that stresses to the healing tissue that remained below failure threshold would be beneficial and that rehabilitation programs designed to limit stresses may negatively affect ultimate outcome. This postulation was supported by Hannafin et al[23] who performed an in vitro study on the effects of stress deprivation on canine tendon. Their results showed a significant decrease in tensile strength over 8 weeks. They suggested that stress may be necessary for optimal graft healing and collagen formation.

TRADITIONAL REHABILITATION

These basic science studies led to the belief that intra-articular graft healing was a long-term process that included a maturation phase in which the graft was necrotic and weak. In an effort to protect the graft, emphasis was placed on immobilization, extension limitation, restricted weight bearing, and delayed return to activity.

In 1981, Paulos et al[1] published the specifics and rationale of their postoperative rehabilitation program for patients following ACL reconstruction *(Figure 1)*. Although they openly stated that their rehabilitation program was based on preliminary findings,opinions and designed to protect all patients, many practicing clinicians quickly adopted this protocol.[2,23,24] The rehabilitation program consisted of five phases that included maximum protection (12 weeks), moderate protection (24 weeks), minimum protection (48 weeks), return to activity (60 weeks), and activity and maintenance.

During the maximum protection phase, patients were placed in a cast, nonweight- bearing (NWB) for 6 weeks in 30° to 60° of flexion. Based on animal research, they estimated healing ligament strength at less than 50% by 12 weeks. Full weight-bearing (FWB) was not allowed prior to 16 weeks. Quadriceps activity was limited through the first 24 weeks to minimize risk to the ACL, while emphasis was placed on hamstring strengthening. Running began approximately 9 to 12 months after surgery when the operative leg achieved 75% strength of the normal leg. The authors recommended a minimum of 9 months to return to full activity with most patients requiring at least a year.

A 1980 international survey performed by Paulos et al[1] revealed that 53% of responding knee experts initiated knee motion by 3 weeks. The authors were concerned that the early initiation of knee motion could disrupt attachment site fixation. Of those included in the survey, 75% recommended an immobilization position of 30-60 degrees. The mean time for FWB was 7.7 weeks. The authors cautioned progression to early weight-bearing due to animal studies that demonstrated early graft vascularization at 8 weeks. Full range of motion (ROM) was expected at 6 months by 88% of respondents and the mean time for maximum knee motion was 4.3 months. The majority (63% always, 22% sometimes) felt a brace should be used for protection. Most respondents allowed running by 6 months with the mean at 4.7 months. Mean time for return to full activity was 9.4 months.

TRENDS IN THE 1980'S

Many researchers continued to study graft remodeling and revascularization as graft integrity and viability following ACL reconstruction remained a concern. Studies challenged the standard treatment of immobilization following ACL reconstruction and showed the beneficial effects of immediate joint motion.[25,26] In turn, authors reported performing motion exercises sooner following reconstruction. Noyes et al[27] reported that utilization of early motion avoided knee stiffness and promoted full knee extension following ACL reconstruction. Their early motion program utilized continuous passive motion (CPM) during hospitalization. Upon discharge a knee splint was worn which allowed an immediate arc of 0° to 90° of flexion and the patient used the opposite leg to assist motion for 10 to 15 minutes every hour. In 1987, Noyes et al[28] studied the effects of early knee motion following open and arthroscopic ACL reconstruction. Eighteen patients with acute and chronic ACL deficiencies were randomized into two groups prior to surgery. The motion group started knee motion on the second postoperative day while the delayed motion group initiated motion on the seventh postoperative day. All other aspects of the rehabilitation program were the same. Results showed that CPM performed on the second postoperative day did not increase joint effusion or result in stretching of the ligamentous reconstruction as measured by a KT-1000 arthrometer at 6 months postoperatively. Although not significant, the early motion group also achieved increased mean knee extension and flexion values measured at 1, 2, 3, 4, and 12 weeks postoperatively. Despite the apparent benefits of early motion following ACL reconstruction, the authors were still concerned that utilization of a CPM after reconstruction would disrupt or loosen the graft.[29]

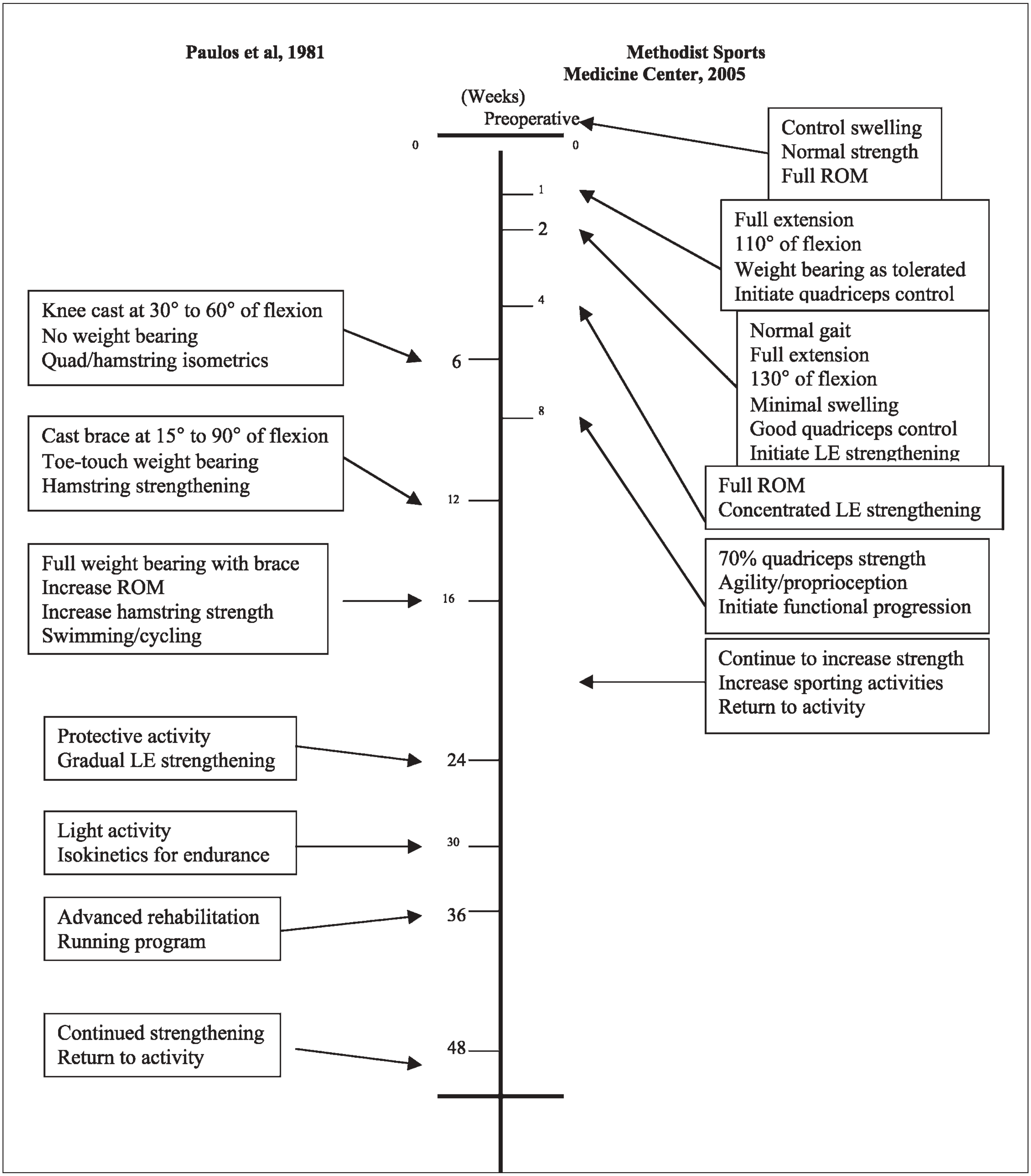

Figure 1. Comparison between traditional rehabilitation as described by Paulos et al[1] and the Methodist Sports Medicine Center Rehabilitation program.

In 1986, Bilko et al[30] published the results of a questionnaire taken at the ACL Study Group meeting in 1984. The survey results were compared to the results of the 1980 international survey by Paulos et al.[1] Analysis of 44 returned questionnaires indicated that more surgeons immobilized the knee between 30° and 60° of flexion, yet the length of time immobilized decreased. Of those who responded, 48% were immobilized between 1 and 3 weeks compared to 21% who were immobilized between 5 and 8 weeks. Isometric exercises were not prescribed as often during the 1st week postoperatively, while the use of electrical stimulation and isokinetics during rehabilitation occurred more frequently. The earliest time to full weight-bearing ranged from the 3 to 4 week period to 16 weeks. Less than 7% indicated regular use of continuous passive motion. Full ROM was expected at 3 months by 18% and 6 months by another 68% following ACL reconstruction. Only one surgeon responded that the minimum time for return to full activity was 6 months, while 95% reported return within 10 months postoperatively. All respondents allowed return to full activity by one year. Only 25% did not recommend a brace for return to play.

Despite achievement of good ligamentous stability, patients often experienced a spectrum of complications that included patellofemoral symptoms, quadriceps weakness, and limited ROM.[31-33] From 1982 to 1986, Sachs et al[34] prospectively followed 126 patients who underwent ACL reconstruction and were immobilized in 30° of flexion for 3 weeks. At one-year follow-up, quadriceps weakness was defined as less than 80% bilaterally and was present in 65% of patients which correlated positively with flexion contracture and patellar irritability. Flexion contractures ≥ 5° were present in 24% of patients and patellofemoral pain occurred in 19% of patients. Sachs et al[35] also published results from the San Diego Kaiser review series of 390 patients with ACL surgeries between 1983 and 1988. One year follow-up statistics revealed 3% of patients with postoperative graft impingement, 7% required manipulation, 20% had flexion contractures, 19% experienced patellofemoral pain, 62% demonstrated quadriceps weakness, 12% exhibited an effusion, and 10% required a secondary procedure within 1 year. To decrease the incidence of joint stiffness and flexion contracture, the authors recommended full ROM and no swelling at the time of surgery as well as immobilization of patients at 0° for 10 -14 days postoperatively.

Trends in ACL rehabilitation in the 1980's revealed earlier ROM and weight bearing.[36] Disagreeement was predominant in regard to the initiation of weight-bearing, full ROM, rehabilitation exercises, and return to play. The complication rate remained high during this time but decreased with initiation of earlier motion. It is the senior author's opinion that the rehabilitation programs which were published largely emphasized open kinetic chain (OKC) exercises and hamstring strengthening.[1,24,37]

ACCELERATED REHABILITATION

Rehabilitation of patients following ACL surgery at Methodist Sports Medicine Center initially followed many of the trends begun in the 1980's. In 1982, patients were placed in a cast for 6 weeks following ACL reconstruction. Due to flexion contractures, strict immobilization was replaced in 1983 with the immediate use of a CPM and a 30° removable splint. Like many clinics, the rehabilitation protocol was slightly modified from that used by Paulos et al .[1] Patients did not weight bear until 6 weeks, attain full motion until 4 months, or return to activity until 9 to 12 months postoperatively. By 1985, patients were placed in a 0° postoperative splint. Consequently, motion problems decreased while stability remained unchanged. In 1985, the staff studied patient compliance and found that good clinical results, such as full ROM, strength, stability, and return to activity, were not necessarily correlated with subjectively reported patient compliance (unpublished data). In fact, patients who were noncompliant actually had better results than those who complied with the rehabilitation program. Subsequently, a new criterion-based rather than time-based rehabilitation protocol was adopted at Methodist Sports Medicine Center by the end of 1986.

In 1990, Shelbourne and Nitz[2] published a clinically based article on accelerated rehabilitation of patients following autogenous bone-patellar tendon-bone (BPTB) ACL reconstruction. The accelerated program called for rapid advancement of goals and emphasized early full knee extension, quadriceps muscle leg control *(Figure 1)*, soft tissue healing, and normalized gait pattern. Patients were not immobilized following surgery. On day 1, CPM was initiated and weight bearing as tolerated was allowed without crutches. Strengthening exercises were predominantly closed kinetic chain (CKC) and OKC quadriceps exercises were minimized. Patients typically returned to light sports activities by 2 months and full activity between 4 and 6 months following reconstruction. Subjective and objective follow-up evaluations were routinely performed, as were isokinetic and KT-1000 evaluations beginning 5 to 6 weeks postoperatively. Shelbourne and Nitz[2] reported increased patient compliance, earlier return to normal function, decreased frequency of patellofemoral symptoms, and a significant decrease in the number of procedures required to obtain full knee extension.

Shelbourne and Nitz[2] reported a retrospective comparison of follow-up data on 138 patients who performed a traditional rehabilitation program following ACL reconstruction from 1984 to 1985 and 247 patients from 1987-1988 who performed the accelerated rehabilitation program following ACL reconstruction. Subjective knee ratings were similar for both groups from the time of reconstruction to 2-year follow-up. Isokinetic quadriceps strength tests revealed a quicker return of quadriceps strength in the accelerated group at each follow-up period from 4 months to 1 year. Likewise, analysis of KT-1000 scores revealed equal to or better scores than the traditional group at each follow-up comparison from 4 months to 1 year, which indicated no loss in knee stability. Furthermore, 12% of patients who performed the traditional rehabilitation program required surgical intervention to achieve full extension compared to 4% of patients in the accelerated program.

TRENDS IN THE 1990'S:
EVIDENCE FOR ACCELERATED REHABILITATION

The accelerated program was met with much resistance in the literature. Many authors were concerned that "aggressive" rehabilitation would lead to graft failure,[14,38] inappropriate graft strain,[39-43] or adversely affect articular cartilage.[40] Several authors cited that there was no evidence to support the safety of activities such as early FWB, jogging and agility drills by 5 to 6 weeks, return to sport at 4 to 6 months,[43-45] and were alarmed by the lack of long-term follow-up.[38,39,43,46]

Devita et al[45] reported that gait mechanics were abnormal following accelerated rehabilitation while Hardin et al[47] suggested that individuals with hyperlaxity had an increased risk for instability following accelerated rehabilitation. Beynnon and Johnson[44] questioned the safety of accelerated rehabilitation citing the retrospective nature and possible bias as caution for clinical use.

Figure 2. Heelslides are used to attain knee flexion.

Accelerated rehabilitation has been previously described in detail.[2,48-52] The Methodist Sports Medicine Center rehabilitation program outlined in Figure 1 was largely based on the principles of the accelerated protocol.[2] The goal of the Methodist Sports Medicine Center rehabilitation protocol had always been to minimize postoperative complications and return the knee to a normal state as quickly and safely as possible. The protocol continued to be adapted and changed based on clinical experience and the current findings in the literature. With the emergence of evidence-based practice (EBP), much of the accelerated rehabilitation program following autogenous BPTB ACL reconstruction had been well supported in the literature. The term "accelerated" rehabilitation may no longer be appropriate or necessary due to the shift in rehabilitation trends over the past decade.

The Methodist Sports Medicine Center rehabilitation protocol was divided into 5 phases: preoperative, early postoperative, intermediate postoperative, advanced rehabilitation, and return to activity. The time frames presented with each phase were general in nature and based on clinical experience. Progression of patients between phases of rehabilitation were individualized decisions determined by achievement of goals and clinical reasoning.

Phase I: Preoperative

Phase I rehabilitation began immediately following ACL injury.[49] The goals of the preoperative period were to reduce swelling and restore normal motion, gait, and strength prior to surgery. Common exercises for flexion ROM included heel slides *(Figure 2)*, wall slides, and active/assistive flexion. Exercises for extension ROM included heel props *(Figure 3)*, prone hangs, and towel extensions. Once full ROM with minimal swelling was obtained, CKC strengthening was begun with exercises such as leg press, _ squats, step downs *(Figure 4)*, stationary bicycle, and step machines. This time frame also allowed for mental preparation and education of surgery and postoperative rehabilitation. Surgery was scheduled once these goals were attained. The patient underwent preoperative testing for postoperative comparison that included bilateral ROM, KT-1000 ligament arthrometry, isokinetic strength evaluation, and a single leg hop test on the non-involved extremity.[50-52]

De Carlo et al[50] reported a retrospective study of 169 patients who underwent autogenous BPTB ACL reconstruction for acute ACL injury. Patients who had reconstruction within the first week after injury had a significantly increased incidence of arthrofibrosis compared to patients who had reconstruction delayed 21 days or more. Patients who had delayed reconstruction also had better ROM and isokinetic strength scores at 13 weeks following reconstruction. Shelbourne and Foulk[53] performed a retrospective review of 143 patients who underwent autogenous BPTB ACL reconstruction within 3 months of injury. Patients were divided into two groups based on when they elected to have surgery. Group 1 delayed surgery a mean of 40 days after injury while group 2 had surgery a mean of 11 days after injury. Results of isokinetic testing determined that patients who delayed ACL reconstruction had significantly better quadriceps strength at 2 and 4 months postoperatively than those who underwent acute surgery. Cosgarea et al[54] and Wasilewski et al[55] have also confirmed earlier return of motion and strength following delayed ACL reconstruction. Two studies have reported that timing of surgery had no effect on extension loss.[56,57] However, both authors defined full extension as 0° rather than the ROM prior to surgery.[56,57] Regardless of the time from injury, the senior author believes the condition of the knee prior to reconstruction (minimal swelling, full hyperextension, near normal strength, and normal gait) were directly correlated with the ability to regain early motion and strength postoperatively.

Figure 3. A heel prop is used to allow the knee joint to hyperextend.

Figure 4. The step-down exercise is used to develop quadriceps strength.

Udry et al[58] studied psychological readiness of the patient undergoing ACL reconstruction. They found that adolescents reported higher preoperative mood disturbance levels compared to adults. However, adolescents also reported higher levels of psychological readiness for surgery than adults. Shelbourne and Rask[59] reported that patients who had a second ACL procedure for the opposite knee experienced a smoother transition following reconstruction than with the initial procedure. For this reason, a thorough preoperative education was incorporated for all patients. These factors are important to consider because of the effort, motivation, and understanding required of postoperative rehabilitation.

Phase II: Early Postoperative

Immediately following surgery, the reconstructed knee was placed in a cold compression cuff with the leg in a CPM machine. Range of motion, quadriceps control, and weight-bearing as tolerated were initiated the day of surgery. The goals for the first postoperative week were to control swelling, obtain full hyperextension, increase passive knee flexion to at least 110°, and establish good quadriceps leg control. The cold compression cuff remained on the knee at all times except when patients performed ROM exercises. The patient remained lying down as much as possible except when exercises were performed or for personal hygiene. Extension ROM exercises, such as heel props and towel extensions, were performed for 10 minutes hourly during the day. Flexion was initiated with the knee rested in the CPM machine set to 110° and held for 10 minutes, four times daily. Early leg control was accomplished with quadriceps setting, straight leg raises, and active knee hyperextension.

By the end of the second postoperative week, the patient should have been able to demonstrate normal gait, full passive extension, 130° of flexion, and good quadriceps leg control. During this week, patients added prone hangs (1-3 lbs could be added if extension was tight) to their daily ROM exercises. Patients were encouraged to stand with their weight over their reconstructed knee with the quadriceps contracted, which locked the knee into full hyperextension. Gait training was necessary if the patient ambulated with a limp or without a normal heel-to-toe pattern. If the patient had full knee hyperextension and ambulated normally, strengthening exercises could be initiated which included seated knee extension from 90° to full terminal knee extension and bilateral half squats.

Lower Extremity Functional Progression for Court Sports

1. Heel raises 10 times (injured leg)
2. Walk at a fast pace full court
3. Jump on both legs 10 times
4. Jump on the injured leg 10 times
5. Jog in a straight line full court
6. Jog around the entire perimeter of the court two times
7. Sprint at 1/2, 3/4 and full speed from the baseline to half court
8. Run figure 8's at 1/2, 3/4, and full speed from the baseline to half court
9. Triangle drills – sprint baseline to half court, backward run to the baseline, defensive slides along baseline, both directions
10. Cariocas (cross-over drill) completed at 1/2, 3/4, and full speed
11. Cutting completed full court at 1/2, 3/4, and full speed

Figure 5. Functional progressions specific to the patient's sport are employed to establish whether or not the patient is ready to return to activity.

Shelbourne et al[60] performed a prospective trial which compared the effectiveness of different methods of postoperative cryotherapy to decrease pain in 400 patients following autogenous BPTB ACL reconstruction. Patients who used a cold compression device had a significantly shorter hospitalization stay compared to patients who used a thermal blanket or ice bag. They used significantly less oral and injectable narcotics compared to patients who used an ice bag. Noyes et al[61] conducted a prospective study of early motion versus delayed motion exercises in 18 patients following ACL reconstruction. Subjects in the early motion group began CPM on the second postoperative day while subjects in the delay motion group were braced in 10° of extension and began CPM on the seventh postoperative day. The results showed no deleterious effects of early motion with regard to knee laxity, joint effusion, hemarthrosis, ROM, use of pain medication, and length of hospital stay. The use of cold compression, CPM, and early active motion allowed for elevation of the leg, patient comfort, and predictable return of motion.

Initially, many authors were hesitant to attain full extension in the early postoperative period.[62] These concerns were based on biomechanical studies that showed maximal flexion and extension of the knee caused increased stress on the intact ACL.[63] However, many authors had reported that gaining extension immediately postoperatively decreased the frequency of flexion contractures.[2,27,28,34,54,64] Rubinstein et al[65] reviewed the effects of restoring full knee hyperextension immediately following autogenous BPTB ACL reconstruction. Subjects were grouped according to the degree of hyperextension. Group 1 consisted of 97 patients who hyperextended an average of 10° (8°-15°) and group 2 consisted of 97 patients who hyperextended an average of 2° (0 - 5°). No significant differences in KT-1000 arthrometer manual maximum side-to-side scores between groups were found. The authors determined that restored full knee hyperextension immediately postoperatively did not adversely affect stability of the knee.

Several authors had voiced concern that early weight-bearing may have caused excessive forces that harm the graft or fixation and suggested 4 to 6 weeks of crutches to allow for bone healing.[43,62,66,67] However, Arnoczky[68] reported that a biologic graft was the strongest the day it was placed inside the knee. A prospective, study by Tyler et al[69] sought to determine the effect of immediate weight-bearing after autogenous BPTB ACL reconstruction. Forty-nine subjects were randomized into two groups. Group 1 underwent immediate weight-bearing as tolerated while group 2 was nonweight-bearing for 2 weeks. Results showed that immediate weight-bearing after ACL reconstruction resulted in a lower incidence of anterior knee pain, greater vastus medialis oblique electromyography activity, and no effect on knee stability at a mean follow-up of 7.3 months.

Phase III: Intermediate Postoperative

The third and fourth week following reconstruction was the intermediate postoperative phase. During this period, strengthening was initiated cautiously as full ROM was obtained. Strengthening progressed as long as minimal swelling and full ROM were maintained. Exercises were predominantly unilateral, high repetition/low resistance, and CKC exercise during this period and included step downs, leg press, leg extension, and half squats. At the end of 4 weeks, patients underwent passive ROM testing and completed their first postoperative isokinetic strength evaluation and KT-1000 ligament arthrometer tests.

Strain studies indicated that CKC exercises allowed increased muscle activity without subjecting the ACL to increased strain values.[70-72] A prospective study by Bynum et al[73] compared OKC versus CKC exercises during rehabilitation following authogenous BPTB ACL reconstruction. Ninety-seven patients were randomized to the OKC and CKC protocols. Results at a mean follow-up of 19 months demonstrated that CKC exercise following ACL reconstruction resulted in less patellofemoral pain and better subjective scores than OKC exercise. Subsequently, the authors reported using CKC exercise exclusively following ACL reconstruction. A prospective study by Mikkelsen et al[74] compared CKC versus combined CKC and OKC exercise initiated 6 weeks after ACL reconstruction. Forty-four patients were randomized into the two groups. Follow-up at 6 months indicated that the addition of OKC exercise produced a significant improvement in quadriceps strength, earlier return to sport, and no increased KT-1000 measurements. Although caution was used with full arc OKC exercise, the Methodist Sports Medicine Center protocol included integration of both OKC and CKC exercises.

Phase IV: Advanced Rehabilitation

Weeks five through eight comprised the advanced rehabilitation phase. The emphasis of this phase was increased strength and initiation of early sports activities. The patient continued to maintain full ROM and advanced strengthening to low repetition/high resistance as indicated. Once patients demonstrated 70% quadriceps strength via isokinetic testing, they performed light agility drills and proprioceptive activity that included a running progression, lateral slides, crossovers, and single leg hopping. If a joint effusion was present, it was carefully monitored as activity increased. An activity-specific functional progression, such as shooting baskets or dribbling a soccer ball, was initiated near the end of this period. At the end of 8 weeks, the patients were evaluated to assess ROM, tested with the KT-1000 ligament arthrometer, performed an isokinetic strength evaluation, and completed a subjective questionnaire.

In 1993, Barber-Westin and Noyes[39] reported serial KT-1000 measurements on 84 patients following BPTB allograft ACL reconstruction and controlled rehabilitation for chronic ACL deficiency. Arthrometer measurements were obtained on each patient for at least 2 years following surgery. Of those patients with abnormal anterior-posterior displacements greater than 2.5 mm, 86% were first detected during the intensive strength training or return to sports phases of rehabilitation. In 1999, Barber-Westin et al[40] reported a subsequent observational study of 142 patients following ACL reconstruction that used a rehabilitation program similar to the previous study. However, this group of subjects used a BPTB autograft rather than an allograft. They found no association between abnormal displacements and the phase of rehabilitation.

Shelbourne and Davis[75] followed 603 patients who underwent autogenous BPTB ACL reconstruction and participated in a sports agility program at a mean of 5.1 weeks. These patients were evaluated to determine if program effected knee stability. Patients were required to have full hyperextension, knee flexion to 120°, and at least 60% quadriceps strength compared to the normal leg. The KT-1000 manual maximum arthrometer scores revealed that 92.7% of patients at a mean of 5 weeks and 93.2% of patients at a mean follow-up of 24 weeks had displacement differences of 3 mm or less. The results showed that early return to sports agility activities did not compromise graft integrity measured 24 weeks following ACL reconstruction.

Phase V: Return to Activity

Return to activity was very individualized and was designed to match the patient's goals. The patient continued to increase strength and increase the intensity and duration of athletic activities. A functional progression *(Figure 5)* that followed a half to three-quarter to full speed progression of sport-specific activities was incorporated in this phase. The patient achieved 85% quadriceps strength and completed a functional progression program prior to return to full athletic activity. While some patients returned to activity as early as 2 months, typically patients returned to full activity between 4 and 6 months after ACL reconstruction.

Many authors continued to base return to activity guidelines on histological studies that reported full maturation and required 12 months to complete.[76] However, Rougraff et al[16] reported that ligamentization could require up to 3 years to complete. Glasgow et al[77] studied the effects of early (5 months) versus late (9 months) return to vigorous cutting activities on outcome in 64 patients following patellar tendon autograft ACL reconstruction. Return to vigorous activity was based on a minimum of 8 weeks postoperation, negative Lachman test, absence of effusion, and patient desire to return. At a mean follow-up of 46 months, no differences were found in KT-1000 scores, subjective evaluations, or isokinetic strength. Interestingly, in a review of 1288 patients who underwent autogenous BPTB ACL and accelerated rehabilitation, Shelbourne and Davis[75] reported that more patients tore their normal, contralateral ACL (4.4%) than their reconstructed ACL (2.4%). They proposed that graft failure was not the result of a weakened graft, but rather the consequence of normal return to sport.

In 1995, Shelbourne et al[78] reported KT-1000 manual maximum difference scores in a 2 to 6 year follow-up of 209 patients after autogenous BPTB ACL reconstruction and accelerated rehabilitation. The mean KT-1000 score was 2.06 mm at full ROM and 2.10 mm at a mean 2.7 year follow-up. In 1997, Shelbourne and Gray[79] reported objective data on 806 patients and subjective data on 948 patients in a 2 to 9 year follow-up after autogenous BPTB ACL reconstruction and accelerated rehabilitation. Of those patients who underwent acute reconstruction, the mean manual maximum KT-1000 arthrometer difference was 2.0 mm with 90% of patients less than or equal to 3 mm and 98% of patients less than 5 mm of laxity. No joint space narrowing was seen in 94% of patients, isokinetic quadriceps evaluation revealed 94% strength, mean motion was 5° of hyperextension and 140° of flexion, and mean subjective modified Noyes questionnaire[87] score was 93.2 out of 100 possible. In 2000, Shelbourne and Gray[79] reported on the effects of meniscus and articular cartilage status on autogenous BPTB ACL reconstruction and accelerated rehabilitation in a 5 to 15 year follow-up. Of those patients with both menisci present and normal articular cartilage at the time of surgery, 97% had normal or near normal radiographs. Based on these findings, evidence supported that accelerated rehabilitation following autogenous BPTB ACL reconstruction produced excellent long-term results without affecting long-term stability.

Trends in ACL rehabilitation in the 1990's revealed remarkable changes compared to the 1980's. Many authors began adopting protocols similar to the accelerated program.[80-85] The rehabilitation programs were characterized by preoperative rehabilitation, immediate ROM and weight bearing, full passive knee extension, and functional exercise. Meanwhile, some authors continued to share concerns regarding the wide scale use of these new protocols, particularly in specific patient groups or with specific graft sources.[40,45,46]

ACL REHABILITATION IN THE 2000'S: EVIDENCE-BASED PRACTICE

Recently, the buzzword in the physical therapy profession has been "evidence-based practice." Evidence based practice is a very positive trend that may ultimately result in improved quality and effectiveness of patient care. Sackett et al[86] defined EBP as "the integration of best research evidence with clinical expertise and patient values." Evidence based practice could be the trend that defines ACL rehabilitation in the 2000's.

Several authors[41,44,70,87] have published well-conducted research on the strain behavior of the ACL during common rehabilitation activities. A comprehensive database has been compiled based on peak strain values in which the authors used to design rehabilitation programs to be compared in a prospective, randomized, double-blind trial. The results of these studies will help delineate rehabilitation programs that are safe for a healing ACL graft. A need exists for prospective, randomized, blinded clinical trials to compare accelerated rehabilitation with more conservative rehabilitation before accelerated rehabilitation can be considered safe and appropriate.[88]

Recently, Beynnon et al[89] reported the results of a prospective, randomized, double-blind study comparing accelerated versus nonaccelerated rehabilitation in 22 patients following BPTB ACL reconstruction. The rehabilitation programs were based on their previous work of ACL strain data during rehabilitation activities. Exercises that had been shown to produce significant strain to the ACL were initiated earlier in the accelerated program and delayed in the nonaccelerated program. Exercises that did not produce significant ACL strain were initiated in both rehabilitation programs during the same time frame. The accelerated program, characterized by early unrestricted weight-bearing and early use of quadriceps-dominated exercises, lasted 19 weeks and return to sports was possible by 24 weeks while the nonaccelerated program lasted 32 weeks and return to sports was possible also at 32 weeks. At 2-year follow-up, their results demonstrated no difference in anterior knee laxity between accelerated and nonaccelerated rehabilitation. The authors also found that both programs produced the same outcomes in clinical assessment, patient satisfaction, functional performance, and articular cartilage metabolism. Furthermore, total compliance measured at the end of each program was significantly less in the nonaccelerated group.

Evidence based practice has not been limited to prospective, randomized, blinded clinical trials.[90] While the authors agree that prospective, randomized, blinded clinical trials are the gold standard and large studies of this nature are required for best evidence practice, the difficulty most clinicians face in performance of such studies must be acknowledged. Prospective long-term outcome studies may also be conducted to gain insight into the effectiveness of clinical intervention.

To date no studies have been published that have determined conservative rehabilitation following ACL reconstruction to have produced better outcomes or long-term stability than those reported with accelerated rehabilitation. Therefore, the current evidence supports the use of the more physiologic progression following BPTB ACL reconstruction.

While research evidence has been a very important part of EBP, it is the senior author's opinion that clinical expertise and patient values are equally important components of EBP for quality patient care. Salter[91] reported that the biological concept of CPM for synovial joints was based on clinical observation and deduction. In 1970, the concept of CPM was introduced which was contrary to the initial thought process of joint immobilization for disease or injury.[91] The evolution of the Methodist Sports Medicine Center rehabilitation protocol following ACL reconstruction was based on clinical experience and listening to patients.[2,49-51] In 1990, accelerated rehabilitation was the antithesis of traditional rehabilitation following ACL reconstruction.[2]

The clinician must utilize clinical reasoning skills and individualize the care of each patient. No specific exercises or parameters exist for exercise intensity or duration that have been proven to lead to successful outcomes. Guidelines for early application of strain to the healing ACL have not been published. The Methodist Sports Medicine Center rehabilitation protocol the authors have presented has adhered to the basic principles of rehabilitation. Patients increased activity if they had attained full ROM, exhibited minimal effusion and pain, had a normal gait, and demonstrated good leg strength measured isokinetically (quadriceps deficit of ≤30%). The condition of the knee dictated rehabilitation. Patients were not forced to return to activity. Only when the patient was physically and mentally ready was return to activity considered. In addition, the use of a functional progression program allowed the patient and the physical therapist, athletic trainer and, in rare instances, the coach to determine if an athlete was ready to advance.

RE-EMPHASIS IN ACL REHABILITATION

Many researchers have attempted to replicate the accelerated Methodist Sports Medicine Center rehabilitation protocol[45,46,91] or currently utilize a similar protocol. For this reason, the authors felt that it was important to clear some misconceptions and re-emphasize some key points of the Methodist Sports Medicine Center rehabilitation protocol.

The preoperative period was vitally important for successful outcome following ACL reconstruction.[49,50,52,93] Patients were required to have full ROM including hyperextension, minimal effusion, good quadriceps strength via isokinetic testing, and normal gait prior to reconstruction. Once these goals were met, surgery was scheduled at a time that was convenient for the patient to allow restricted activity during the first postoperative week.

The emphasis of the first postoperative week was the minimization of swelling.[49,59,60] If swelling could be prevented, motion and strengthening would not be inhibited. Although immediate full weight bearing as tolerated with crutches was allowed, activity was not unrestricted. The patients were instructed to remain supine with the leg in the CPM machine except when performing exercises or personal hygiene.[50] The ability to prevent swelling during the first postoperative week greatly impacted the progression of return to activity.

Restoration of motion should be aimed to achieve motion equal to the opposite extremity. Normal motion was often thought of as 0° to 135°.[46,56,57,66,89] However, a study by De Carlo and Sell[94] of 889 preseason athletes found that 96% of individuals demonstrated some degree of hyperextension. The mean ROM was 5° of hyperextension and 140° of flexion for males and 6° of hyperextension and 143° of flexion for females. If the patient had not achieved full ROM, especially hyperextension, equal to the opposite side, the return of normal gait, function, and knee biomechanics would have been inhibited. The importance of obtaining full hyperextension postoperatively has been well documented.[2,16,27,28,34,54,64]

The Methodist Sports Medicine Center rehabilitation protocol was criterion-based.[49] The time frames given were used as guidelines and were not absolute. Advancement to the next phase depended on the condition of the knee and completion of the goals of the previous phase. The initial phases of the program were very similar for all patients in an attempt to restore normal motion, gait, and strength. The latter phases of the program were much more individualized in an effort to return patients to their previous level of function.

CONCLUSION

Over the past two decades, rehabilitation of a patient after an ACL injury has made a dramatic shift toward better patient outcomes and quicker return to activity. In their respective times, the traditional and accelerated rehabilitation models have both given clinicians a sound framework for treating patients as well as stimulated further research. A solid base of evidence exists in the literature to support accelerated rehabilitation as both safe and effective. As EBP and the call for prospective, randomized clinical research continues, the continued progress in treating this injury is exciting. Furthermore, clinicians are urged not to lose sight of the clinical reasoning and deduction that assisted in the evolution of the current science of ACL rehabilitation.

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CASE REPORT

USE OF KNEE EXTENSION DEVICE DURING REHABILITATION OF A PATIENT WITH TYPE 3 ARTHROFIBROSIS AFTER ACL RECONSTRUCTION

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ABSTRACT

Background. Arthrofibrosis is a frequent complication following rehabilitation of a patient with anterior cruciate ligament (ACL) reconstruction. Although prevention is the best treatment, little information exists within the literature regarding the management and rehabilitation intervention for arthrofibrosis. In this case report a rehabilitation program in the treatment of a patient with arthrofibrosis is described.

Objectives. To identify the importance of discrete measures of knee range of motion in the knee of a patient following ACL reconstruction in order to help prevent postoperative complications.

Case Description. The patient was an 18-year-old female who sustained an ACL and medial collateral ligament (MCL) injury in a basketball game and underwent an ACL reconstruction with an ipsilateral patellar tendon graft. The patient developed arthrofibrosis and, despite traditional physical therapy of therapeutic exercise and manual therapy, the patient continued to complain of pain, stiffness, limited activities of daily living, and the inability to participate in competitive sports. This patient used a knee extension device as part of her rehabilitation program.

Outcomes. The patient was able to obtain knee extension and flexion equal to her opposite normal knee. Upon completion of the rehabilitation program, the patient returned to full activities of daily living and competitive sports.

Discussion. Increasing and maintaining knee extension that is equal to the opposite normal knee is an important component in the successful outcome for the patient after ACL reconstruction. The use of a knee extension device may provide an effective rehabilitation intervention in the treatment of arthrofibrosis.

Key Words: arthrofibrosis, anterior cruciate ligament, rehabilitation

INTRODUCTION

Arthrofibrosis is an abnormal proliferation of fibrous tissue in and around a joint that can lead to loss of motion, pain, stiffness, muscle weakness, swelling, and limited activities of daily living. This condition can occur after an injury, or more commonly, after surgery.[1-12] Arthrofibrosis remains a common postoperative complication after anterior cruciate ligament (ACL) reconstruction despite the choices of graft selection. Patellar tendon grafts, hamstring grafts, and allografts are the most commonly used grafts selected for ACL reconstruction, and arthrofibrosis has been found to occur after all three. While a greater incidence of arthrofibrosis occurs with a patellar tendon graft, this condition continues to be prevalent in patients who received hamstring grafts and allografts, as well.[13,14]

Shelbourne et al[10] classified different types of arthrofibrosis in the knee based on the loss of knee extension, flexion, or both; the location of scar tissue formation intra-articularly; and the mobility and location of the patella *(Table 1)*. Prevention of arthrofibrosis is the preferred treatment and is possible with a structured rehabilitation program.[12] However, once arthrofibrosis has occurred, the treatment approach widely varies. Numerous published surgical reports exist regarding the cause and treatment of arthrofibrosis, but the rehabilitation programs are poorly defined.[1,3,5-7,9] For the physical therapist, even fewer guidelines exist with no consistent consensus among researchers as to the most effective treatment and postoperative

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Table 1. Classification of Arthrofibrosis.

TYPE	EXTENSION	FLEXION	PATELLAR MOBILITY
Type 1	<10° extension loss	Normal flexion	Normal
Type 2	>10° extension loss	Normal flexion	Normal
Type 3	>10° extension loss	>25° flexion loss	Decreased
Type 4	>10° extension loss	>30° flexion loss	Decreased and patella infera

rehabilitation.

The importance of obtaining and maintaining knee extension following ACL reconstruction is well documented in the literature.[1,4,10-12,15] Most treatment approaches for arthrofibrosis include surgical intervention followed by extension casting and "aggressive" physical therapy. Published reports discuss the use of serial casting, "drop out" casts and daily physical therapy.[8,10] This approach is often a time consuming event requiring daily cast changes and multiple visits to the clinic or hospital. However, the best treatment approach in achieving range of motion (ROM) after surgical intervention requires further investigation. Many times, patients with arthrofibrosis will undergo multiple surgeries and extended lengths of time in physical therapy, which can become very costly and time consuming.

The purpose of this case report is to describe the use of a knee extension device in the treatment of a patient with Type 3 arthrofibrosis. In this case a unique knee extension device was used as part of a home exercise program.

Table 2. Order of events following previous treatment.

EVENT	DATE	RIGHT KNEE ROM
Date of Injury	10-28-03	
ACL Reconstruction	12-09-03	0-0-45°
Manipulation	02-06-04	0-3-90°
Manipulation	03-22-04	0-10-108°
Follow-up appointment	05-13-04	0-7-120°

CASE DESCRIPTION

The patient was an 18-year-old female who tore her right ACL and medial collateral ligament during a basketball game on 10-28-03. She was evaluated by an orthopedic surgeon and placed in a knee brace that was locked at 30°. The patient was instructed by the physician to perform quadriceps muscle contractions and straight leg raise exercises. She underwent medial collateral ligament repair and ACL reconstruction using an ipsilateral patellar tendon graft on 12-09-03. After surgery, the patient's knee was kept in extension by a knee brace and she was limited to toe touch weight bearing for four weeks.

The patient began formal physical therapy for ROM and patellar mobilization on 12-31-03 and was advised by her physician to continue to wear the knee brace locked at 0° to 90°. Due to the slow progress in ROM, the patient underwent a right knee manipulation and arthroscopy on 02-06-04. After surgery, the patient continued with physical therapy for ROM exercises and was prescribed methylprednisolone (steroid for inflammation). Over the next month, the patient had her knee aspirated twice, was placed on rofecoxib (non-steroidal anti-inflamatory – NSAID), and repeated a dose of methylprednisolone. The patient continued to complain of pain and stiffness in her right knee. As of 03-19-04, her right knee ROM was still significantly limited at 0-10-108°.

The patient underwent a second right knee manipulation and arthroscopy on 03-22-04 *(Table 2)*. Postoperatively, the patient was placed on prednisone (steroid for inflammation) and issued a continuous passive motion (CPM) machine to assist with ROM. Upon follow up, the patient was diagnosed with arthrofibrosis. She was instructed to continue with physical therapy and placed on cyclobenzaprine, a muscle relaxer. She additionally received bupivacaine (analgesic for pain) injections prior to physical therapy appointments to help make her physical therapy more tolerable. She was attempting to run and bike but continued to have significant pain and stiffness. The patient was then referred to the Shelbourne Clinic at

Methodist Hospital for a second opinion on examination and treatment of her knee on 05-25-04.

Initial Physical Therapy Examination

Physical examination showed that the patient had an antalgic gait and was walking with a bent right knee. She had right quadriceps atrophy. The patient's knee had a mild effusion, good patella mobility in all directions, a negative Lachman test, negative posterior drawer, and negative varus and valgus laxity with testing. The patient felt no tenderness to palpation over the medial collateral ligament or the patellar tendon. She was able to perform a leg raise with a bent knee and significant extension lag. Plain radiographs were read as normal.

Range of motion measurements were taken using a goniometer as described by Norkin.[16] ROM measurements were recorded as A-B-C, with A being the degrees of hyperextension, B indicating lack of extension from zero, and C documenting degrees of flexion.[17] Her right knee ROM was 0-10-110° vs. her normal left knee 10-0-150°, which means she was lacking 20° of extension and 40° of flexion.

The International Knee Documentation Committee subjective knee form (IKDC) outcome instrument was used to assess the patient's current condition.[18] The initial score on the IKDC was 41/100 and is representative of a significant amount of disability.

The patient was diagnosed with Type 3 arthrofibrosis. The patient had been undergoing regular physical therapy in her home town three times per week since her ACL reconstruction. After discussing the details of the physical therapy sessions, it became apparent that the focus of the rehabilitation program had been on strengthening and not ROM. Therefore, the present focus was to try non-operative methods to maximize her knee ROM and restore knee symmetry. The goals of physical therapy were to increase right knee ROM equal to her left knee, decrease swelling, restore a normal gait pattern, increase leg strength equal to her left knee, and return to normal activities of daily living and eventually full competitive basketball.

Physical Therapy Intervention

The loss in knee extension is more problematic and causes more limitations than a loss of knee flexion.[1,8] Aglietti et al[1] showed that patients who have better knee ROM before surgery have a better prognosis and outcome after surgical intervention. Therefore, the initial plan of care focused on treating the knee extension loss. Paulos et al[8] showed that it is difficult to obtain and maintain both flexion and extension at the same time and achieving extension should be a priority. The treatment was initiated to focus on increasing knee extension only. Most uninjured, normal knees have some degree of hyperextension. De Carlo and Sell[17] found normal knee extension to be 5° of hyperextension in males and 6° of hyperextension in females. Normal knee ROM is defined as ROM equal to that of the noninvolved limb to include the measurement for hyperextension. The patient's normal, uninvolved knee extension measured 10° of hyperextension. Therefore, our goal was to maximize knee extension equal to the opposite normal knee.

A knee extension device (Elite Seat, Kneebourne Therapeutics, Noblesville, IN) was used that would stretch the knee into hyperextension *(Figure 1)*. The second author (KDS) is a part owner of Kneebourne Therapeutics which designed and developed the knee extension device. This device is patient controlled and provides a low load, long duration stretch.[19] The patient was issued and instructed to use the extension device for 10 minutes 3-4 times per day followed by additional knee extension exercises. These exercises included a towel stretch and heel prop exercises and active terminal knee extension while standing. The towel stretch is an exercise that focuses on increasing extension and forcing the knee into knee hyperextension *(Figure 2)*. The patient was advised in performing a heel prop and it was to be performed whenever the patient was sitting *(Figure 3)*. She was also instructed to stand on the involved extremity and attempt to extend the knee into a locked out posi-

Figure 1: Elite Seat: The Elite Seat is a knee extension device used to increase knee extension.

tion by an active quadriceps contraction *(Figure 4)*. This exercise assisted in maintaining the extension acquired from the previous exercises. All exercises were performed three times per day. The patient received instruction in gait training and was encouraged to walk full weight bearing with a normal, symmetrical gait pattern. Finally, she was issued and instructed in a cold/compression device (Cryo/Cuff, Aircast Inc., Summit, New Jersey, USA) to help control swelling and soreness.

Figure 2: Towel Stretch: The towel stretch exercise is performed to increase knee extension. A towel is placed around the ball of the foot and the opposite hand holds down the distal part of the thigh. The patient pulls the towel up bringing the knee into hyperextension.

Given that the patient lived approximately 5 hours of driving time from the clinic, she was set up on a home exercise program as described previously to focus on increasing and maximizing her involved extremity knee extension. Her progress was monitored through phone calls. Two weeks later she returned for a follow-up evaluation and presented with increased ROM. Her right involved knee measurement was 5-0-110° vs. 10-0-150° in the left normal knee. On physical examination, she was able to perform a straight leg raise and an active heel lift *(Figure 5)*; however, this activity was not equal to the opposite knee. The patient's knee had a mild effusion and she walked with a slightly bent knee. The patient reported that her knee was still very sore. The patient was advised to continue with her current home exercise program focusing on increasing her knee extension until she felt she was no longer making improvements.

Figure 3: Heel Prop: The heel prop is performed by placing a bolster under the patient's heel allowing the knee to fall into hyperextension.

The patient returned 2 weeks later (1 month after her initial visit) to check her progress following this new treatment. She felt she had maximized her knee extension at that time and was feeling most of her discomfort in the anterior aspect of the knee while using the knee extension device and performing the exercises. Upon physical examination, she continued to walk with a bent knee and had a mild effusion. Her ROM measured the same as her previous visit, still lacking both extension and flexion. She continued to have pain with walking, stairs and activities of daily living. The patient's desire was to return to high-level sports and she planned on playing basketball at a college later that year. Given that her knee was still lacking ROM and she was having pain and difficulty with activities of daily living, the patient elected to undergo an arthroscopic scar resection as recommended by the physician.

Surgical Intervention

The patient underwent an arthroscopic scar resection on 07-19-04, approximately 6 weeks after her initial presentation to the present clinic *(Table 3)*. Informed consent was obtained and the rights of the subject were protected for a study in the follow up of patients undergoing knee arthroscopy. She underwent the surgical procedure as described by Shelbourne et al[10] for Type 3 arthrofibrosis.

The patient was kept overnight in the hospital and received intravenous Toradol for inflammation and pain control. An anti-embolism stocking was applied to the patient's leg and the leg was elevated in a CPM machine to help prevent postoperative swelling. She was also placed in a CryoCuff (Aircast Inc., Summit, New Jersey, USA) to assist in preventing a hemarthrosis.

Post Surgical Physical Therapy Intervention and Examination

On the day of surgery, exercises for extension were immediately initiated. The knee extension device was used for 10 minutes, followed by 10 towel stretch exercises, and quadriceps activation to achieve and maintain an active heel lift. She followed this exercise with 10 straight leg raises to maintain good leg control and avoid quadriceps inhibition. These exercises for knee extension were performed six times per day. The patient was on bed rest for the first three days postoperatively to minimize swelling. Bed rest is an important concept after surgery since evidence exists that a hemarthrosis may contribute to an inhibitory effect on the quadriceps and hamstrings muscles resulting in muscle atrophy.[20] Early quadriceps muscle activation plays a key role in achieving and maintaining knee extension.[8] Therefore, although the patient was on bed rest to minimize swelling, she was performing a regular exercise program to achieve and maintain full terminal hyperextension equal to the opposite knee. Full weight bearing with a normal gait pattern was emphasized and allowed for restroom privileges only.

Figure 4: Standing knee lock-out: The patient shifts his/her weight to the involved extremity and forces the knee into hyperextension by a quadriceps contraction.

The patient was discharged from the hospital to a nearby hotel. Prior to discharge, her ROM was 10-0-90° in the right involved knee versus 10-0-150° in the left knee. She had a moderate effusion and walked full weight bearing with a slightly antalgic gait pattern. The patient was discharged from the hospital with a home exercise program. She was to remain supine in the CPM with continuous use of the cold/compression device. Six times throughout the day, she took her leg out of the CPM machine, removed the cold/compression device and performed the exercise program, which included the extension device for 10 minutes, towel stretch exercises followed by active quadriceps muscle activation 10 times, and straight leg raise exercises 10 times. The patient then reapplied the cold/compression device and placed her leg back in the CPM machine. Full weight bearing and a normal gait pattern was encouraged and emphasized for restroom privileges only.

Figure 5: Active Heel Lift: The patient is able to lift his/her heel off the table and make the knee go into hyperextension by contracting the quadriceps muscle.

At three days postoperatively, she returned to the clinic to have her ROM and progress evaluated. She continued to achieve full passive terminal hyperextension equal to the opposite knee, an active heel lift, a straight leg raise, and her knee had a moderate effusion. Knee flexion exercises were instituted because she had excellent leg control and equal knee extension. She was instructed in heel slide and wall slide exercises and was told to discontinue flexion exercises if she noted any loss in knee extension. She was instructed to continue to use the extension device and perform all exercises 3 to 5 times per day. She was told to perform a heel prop exercise when sitting and to stand on the involved extremity forcing the knee locked out by an active quadriceps muscle contraction when standing.

At 10 days postoperatively she had maintained her full passive terminal hyperextension equal to the opposite normal knee, an active heel lift, and was walking with a normal gait. Her knee had a mild effusion and ROM measured as 10-0-125° in the right involved knee versus 10-0-150° in the left normal knee. She was instructed to continue to focus on perfect knee extension and to increase her knee flexion until she could sit on her heels equally and comfortably *(Figure 6)*. No strengthening exercises were initiated so that the focus continued to be on achieving full knee ROM.

She returned 08-31-04, approximately six weeks postoperatively, and she rated her knee at 60% and had returned to all normal activities of daily living including helping out on the family farm. She continued to perform the prescribed exercises four times per day. Her ROM on the right involved knee was 10-0-143° versus 10-0-150° in the left normal knee. She was able to sit on her heels but had an uncomfortable tilt. Her knee had a mild effusion and she had a normal gait, no tenderness, and an active heel lift that was not yet equal to the opposite normal knee. She was instructed to continue with her previous home exercise program but she could gradually decrease using the extension device to 1-2 times per day as long as she did not lose extension. Upon achieving full ROM symmetrically equal to the opposite knee, she was able to begin biking and elliptical cross trainer, single-leg press, single-leg extensions, and step down exercises. These exercises were performed one time per day, 3 - 5 times per week. Progression of the low-impact and strengthening program was allowed as long as no ROM was lost or compromised.

Figure 6: Sitting on Heels: Equal knee flexion can be demonstrated by having the patient sit on his/her heels comfortably and symmetrically.

On 09-23-04, approximately two months after her surgery, she underwent isokinetic strength testing at 180° and 60° speeds and single-leg hop testing.[21] These strength tests were repeated at four, six, and eight months postoperatively. At four months she was allowed to begin shooting baskets and light agility drills. At eight months postoperatively she was released to full participation *(Table 3).*

OUTCOMES

At four months postoperatively, the patient had symmetrical knee ROM including full equal hyperextension and full equal flexion. She had an equal active heel lift and was able to sit on her heels equally and comfortably. Isokinetic strength testing of the involved knee compared with the opposite normal knee revealed 79% strength at 180°/s speed and 66% strength at 60°/s speed. She rated her knee at 80%.

At one year postoperatively, the patient's knee had symmetrical ROM including full equal hyperextension and full equal flexion. She had an equal active heel lift and

Table 3. Order of events using knee extension device.

EVENT	DATE	Right Knee ROM	STRENGTH 180°	STRENGTH 60º	ACTIVITY
Initial Evaluation	05-25-04	0-10-110°			
2 weeks	06-09-04	5-0-110º			
4 weeks	07-06-04	5-0-110º			
Arthroscopic scar resection	07-19-04				
Hospital Discharge	07-20-04	10-0-90º			Bed rest x 3 days
3 days PO	07-23-04	10-0-115º			
10 days PO	08-03-04	10-0-125º			
6 wks PO	08-31-04	10-0-143º			Low impact
2 mos PO	09-23-04	10-0-148º			
4 mos PO	11-16-04	10-0-150º	79%	66%	Shooting baskets
6 mos PO	01-12-05	10-0-150º	74%	75%	Agility drills
8 mos PO	03-09-05	10-0-150º	95%	83%	Return to basketball
1 yr PO	07-19-05	10-0-150º	89%	96%	

PO = postoperatively

was able to sit on her heels equally and comfortably. Her quadriceps muscle strength was 89% of the opposite normal knee at 180°/s speed and 96% strength at 60°/s speed with isokinetic strength testing. She tested 101% on the single-leg-hop test. She rated her knee at 98% and her knee had a mild effusion. The patient's IKDC score at one year postoperatively was 97/100, more than doubling the score she achieved on her initial visit. Additionally the patient returned to full athletic competition without pain or difficulty and was formally discharged from physical therapy at that time.

DISCUSSION

The treatment of arthrofibrosis is often a costly and time intensive treatment process. The focus of treatment in most published articles is in regards to surgical intervention with varying rehabilitation protocols. Authors of previously published papers state the importance of acquiring extension but no consensus exists on the best way to achieve this movement.[2-4,8,11,22] Some authors have tried extension casts which require multiple visits to the clinic and can be very uncomfortable. In addition, a cast prevents the patient from being able to perform exercises in between visits. The use of the extension device used with the patient in this report allowed for a patient controlled intervention in increasing knee extension to include hyperextension.

Although most authors agree that restoration of normal knee ROM is a key tenant of treatment, disagreement exists as to what constitutes "normal" ROM. Other treatment programs to regain knee extension fail to take into account that most people have some degree of knee hyperextension. Many authors report they had achieved good ROM results by achieving zero degrees, however, these authors still did not have a good outcome.[1,5-7,9,22] Achieving full hyperextension equal to the opposite normal knee was the focus of this rehabilitation utilizing the knee extension device. Previous attempts in physical therapy that utilized therapeutic exercises and manual therapy had failed. In this case report, full ROM equal to the opposite normal knee was achieved and it is the author's opinion that this achievement of full extension was the most important factor in returning the patient to an active lifestyle, including competitive basketball.

Maximizing extension preoperatively may have helped in obtaining full extension postoperatively. Avoiding a hemarthrosis and subsequent quadriceps inhibition after surgery allowed for early quadriceps activation and the ability to maintain full terminal knee extension. Once the patient was able to maintain extension, flexion exercises were initiated followed by the rehabilitation program described earlier.

CONCLUSION

While prevention provides the best treatment for arthrofibrosis, a need exists for data on the best way to treat arthrofibrosis once it has occurred. This case is an example of a successful outcome in the treatment of Type 3 arthrofibrosis in which a knee extension device was utilized. The rehabilitation program described in this case study may assist physical therapists and physicians in the treatment of patients with arthrofibrosis.

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INVITED CLINICAL COMMENTARY

PRE-PARTICIPATION SCREENING: THE USE OF FUNDAMENTAL MOVEMENTS AS AN ASSESSMENT OF FUNCTION – PART 2

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ABSTRACT

Part I of this two-part series (presented in the May issue of *NAJSPT)* provided the background, rationale, and a complete reference list for the use of fundamental movements as an assessment of function during pre-participation screening. In addition, Part I introduced one such evaluation tool that attempts to assess the fundamental movement patterns of an individual, the Functional Movement Screen (FMS)™, and described three of the seven fundamental movement patterns that comprise the FMS™.

Part II of this series provides a brief review of the analysis of fundamental movement as an assessment of function. In addition, four additional fundamental tests of the FMS™, which complement those described in Part I, will be presented (to complete the total of seven fundamental tests): shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. These four patterns are described in detail, a grading system from 0-III is defined for each pattern, and the clinical implications for receiving a grade less than a perfect III are proposed.

By reading Part I and Part II, it is hoped that the clinician will recognize the need for the assessment of fundamental movements, critique current and develop new methods of functional assessment, and begin to provide evidence related to the assessment of fundamental movements and the ability to predict and reduce injury. By using such a screening system, the void between pre-participation screening and performance tests will begin to close.

Key Words: pre-participation screening, performance tests, function

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INTRODUCTION

The assessment of fundamental movements is an attempt to pinpoint deficient areas of mobility and stability that may be overlooked in the asymptomatic active population. The ability to predict injuries is equally as important as the ability to evaluate and treat injuries. The difficulty in preventing injury seems to be directly related to the inability to consistently determine those athletes who are predisposed to injuries. In many situations, no way exists for knowing if an individual will fall into the injury or non-injury category – no matter what the individual's risk factors are. Meeuwisse[1] suggested that unless specific markers are identified for each individual, determining who is predisposed to injuries would be very difficult.

The inconsistencies surrounding the pre-participation physical and performance tests offer very little assistance in identifying individuals who are predisposed to injuries. These two evaluation methods do not offer predictable and functional tests that are individualized and may assist in identifying specific kinetic chain weaknesses. Numerous sports medicine professionals have suggested the need for specific assessment techniques that utilize a more functional approach in order to identify movement deficits.[2-4]

The Functional Movement System (FMS)™ is an attempt to capture movement pattern quality with a primitive grading system that begins the process of functional movement pattern assessment in normal individuals. It is not intended to be used for diagnosis, but rather to demonstrate limitations or asymmetries with respect to human movement patterns and eventually correlate these limitations with outcomes, which may lead to an improved proactive approach to injury prevention.[5]

The FMS™ may be included in the pre-placement/ pre-participation physical examination or be used as a stand-alone assessment technique to determine deficits that may be overlooked during the traditional medical and performance evaluations. In many cases, muscle flexibility and strength imbalances may not be identified during the traditional assessment methods. These problems, previously acknowledged as significant risk factors, can be identified using the FMS™. This movement-based assessment serves to pinpoint functional deficits (or biomarkers) related to proprioceptive, mobility and stability weaknesses.

Scoring the Functional Movement Screen™

The scoring for FMS™ was provided in detail in Part I. The exact same instructions for scoring each test are repeated here to allow the reader to score the additional tests presented in Part II without having to refer to Part 1. The scores on the FMS™ range from zero to three; three being the best possible score. The four basic scores are quite simple in philosophy. An individual is given a score of zero if at any time during the testing he/she has pain anywhere in the body. If pain occurs, a score of zero is given and the painful area is noted. A score of one is given if the person is unable to complete the movement pattern or is unable to assume the position to perform the movement. A score of two is given if the person is able to complete the movement but must compensate in some way to perform the fundamental movement. A score of three is given if the person performs the movement correctly without any compensation. Specific comments should be noted defining why a score of three was not obtained.

The majority of the tests in the FMS™ test right and left sides respectively, and it is important that both sides are scored. The lower score of the two sides is recorded and is counted toward the total; however it is important to note imbalances that are present between right and left sides.

Three tests have additional clearing screens which are graded as positive or negative. These clearing movements only consider pain, if a person has pain then that portion of the test is scored positive and if there is no pain then it is scored negative. The clearing tests affect the total score for the particular tests in which they are used. If a person has a positive clearing screen test then the score will be zero.

All scores for the right and left sides, and those for the tests which are associated with the clearing screens, should be recorded. By documenting all the scores, even if they are zeros, the sports rehabilitation professional will have a better understanding of the impairments identified when performing an evaluation. It is important to note that only the lowest score is recorded and considered when tallying the total score. The best total score that can be attained on the FMS™ is twenty-one.

DESCRIPTION OF THE FMS™ TESTS

The following are descriptions of the final four specific tests used in the FMS™ and their scoring system. Each test is followed by tips for testing developed by the authors as well as clinical implications related to the findings of the test.

Shoulder Mobility

Purpose. The shoulder mobility screen assesses bilateral shoulder range of motion, combining internal rotation with adduction and external rotation with abduction. The test also requires normal scapular mobility and thoracic spine extension.

Description. The tester first determines the hand length by measuring the distance from the distal wrist crease to the tip of the third digit in inches. The individual is then instructed to make a fist with each hand, placing the thumb inside the fist. They are then asked to assume a maximally adducted, extended, and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other. During the test the hands should remain in a fist and they should be placed on the back in one smooth motion. The tester then measures the distance between the two closest bony prominences. Perform the shoulder mobility test as many as three times bilaterally *(Figures 1-3).*

Tips for Testing:

- The flexed shoulder identifies the side being scored
- If the hand measurement is exactly the same as the distance between the two points then score the subject low
- The clearing test overrides the score on the rest of the test
- Make sure individual does not try to “walk” the hands toward each other

Figure 1. ***Shoulder Mobility III***

Figure 2 ***Shoulder Mobility II***

Figure 3. ***Shoulder Mobility I***

III

- Fists are within one hand length (Assume one hand length is 8 inches)

II

- Fists are within one and a half hand lengths (Assume one and one half hand lengths is 12 inches)

I

- Fists are not within one and half hand lengths (Beyond 12 inches)

Clearing exam. A clearing exam should be performed at the end of the shoulder mobility test. This movement is not scored it is simply performed to observe a pain response. If pain is produced, a score of zero is given to the entire shoulder mobility test. This clearing exam is necessary because shoulder impingement can sometimes go undetected by shoulder mobility testing alone.

The individual places his/her hand on the opposite shoulder and then attempts to point the elbow upward *(Figure 4)*. If there is pain associated with this movement, a score of zero is given. It is recommended that a thorough evaluation of the shoulder be done. This screen should be performed bilaterally.

Figure 4. ***Shoulder Clearing Test***

Clinical Implications for Shoulder Mobility
The ability to perform the shoulder mobility test requires shoulder mobility in a combination of motions including abduction/external rotation, flexion/extension, and adduction/internal rotation. This test also requires scapular and thoracic spine mobility.

Poor performance during this test can be the result of several causes, one of which is the widely accepted explanation that increased external rotation is gained at the expense of internal rotation in overhead throwing athletes. In addition, excessive development and shortening of the pectoralis minor or latissimus dorsi muscles can cause postural alterations of forward or rounded shoulders. Finally, a scapulothoracic dysfunction may be present, resulting in decreased glenohumeral mobility secondary to poor scapulothoracic mobility or stability.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements of the joints as well as muscular flexibility tests such as Kendall's[6] test for pectoralis minor and latissimus dorsi tightness or Sahrmann's[7] tests for shoulder rotator tightness.

Previous testing has identified that when an athlete achieves a score of II, minor postural changes or shortening of isolated axio-humeral or scapulo-humeral muscles exist. When an athlete scores a I or less, a scapulothoracic dysfunction may exist.

Active Straight Leg Raise

Purpose. The active straight leg raise tests the ability to dis-associate the lower extremity from the trunk while maintaining stability in the torso. The active straight leg raise test assesses active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis and active extension of the opposite leg.

Description. The individual first assumes the starting position by lying supine with the arms in an anatomical position and head flat on the floor. The tester then identifies mid-point between the anterior superior iliac spine (ASIS) and mid-point of the patella, a dowel is then placed at this position perpendicular to the ground. Next, the individual is instructed to lift the test leg with a dorsi-flexed ankle and an extended knee. During the test the opposite knee should remain in contact with the ground, the toes should remain pointed upward, and the head remain flat on the floor. Once the end range position is achieved, and the malleolus is located past the dowel then the score is recorded per the established criteria (explained later). If the malleolus does not pass the dowel then the dowel is aligned along the medial malleolus of the test leg, perpendicular to the floor and scored per the established criteria. The active straight leg raise test should be performed as many as three times bilaterally *(Figures 5-7).*

Tips for Testing:
- The flexed hip identifies the side being scored
- Make sure leg on floor does not externally rotate at the hip
- Both knees remain extended and the knee on the extended hip remains touching the ground
- If the dowel resides at exactly the mid-point, score low

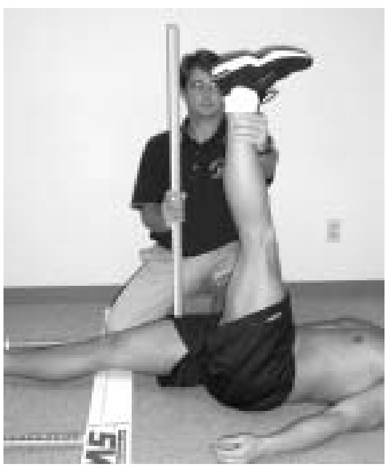

Figure 5. ***Active SLR III***

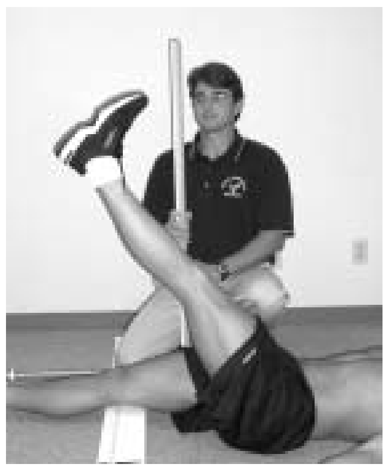

Figure 6. ***Active SLR II***

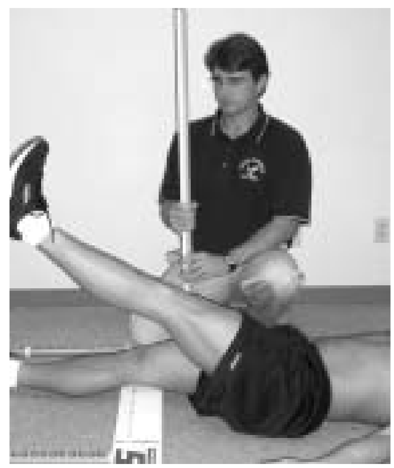

Figure 7. ***Active SLR I***

III
- Ankle/Dowel resides between mid-thigh and ASIS

II
- Ankle/Dowel resides between mid-thigh and mid-patella/joint line

I
- Ankle/Dowel resides below mid-patella/joint line

Clinical Implications for Active Straight Leg Raise

The ability to perform the active straight leg raise test requires functional hamstring flexibility, which is the flexibility that is available during training and competition. This is different from passive flexibility, which is more commonly assessed. The athlete is also required to demonstrate adequate hip mobility of the opposite leg as well as lower abdominal stability.

Poor performance during this test can be the result of several factors. First, the athlete may have poor functional hamstring flexibility. Second, the athlete may have inadequate mobility of the opposite hip, stemming from iliopsoas inflexibility associated with an anteriorly tilted pelvis. If this limitation is gross, true active hamstring flexibility will not be realized. A combination of these factors will demonstrate an athlete's relative bilateral, asymmetric hip mobility. Like the hurdle step test, the active straight leg raise test reveals relative hip mobility; however, this test is more specific to the limitations imposed by the muscles of the hamstrings and the iliopsoas.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by Kendall's sit-and-reach test as well as the 90-90 straight leg raise test for hamstring flexibility. The Thomas test can be used to identify iliopsoas flexibility.[6]

Previous testing has identified that when an athlete achieves a score of II, minor asymmetric hip mobility limitations or moderate isolated, unilateral muscle tightness may exist. When an athlete scores a I or less, relative hip mobility limitations are gross.

Trunk Stability Push-Up

Purpose. The trunk stability push-up tests the ability to stabilize the spine in an anterior and posterior plane during a closed-chain upper body movement. The test asseses trunk stability in the sagittal plane while a symmetrical upper-extremity motion is performed.

Description. The individual assumes a prone position with the feet together. The hands are then placed shoulder width apart at the appropriate position per the criteria described later. The knees are then fully extended and the ankles are dorsiflexed. The individual is asked to perform one push-up in this position. The body should be lifted as a unit; no “lag” should occur in the lumbar spine when performing this push-up. If the individual cannot perform a push-up in this position, the hands are lowered to the appropriate position per the established criteria *(Figures 8-10).*

Tips for Testing:
• Tell them to lift the body as a unit
• Make sure original hand position is maintained and the hands do not slide down when they prepare to lift
• Make sure their chest and stomach come off the floor at the same instance
• When in doubt score it low
• The clearing test overrides the test score

Figure 8. ***Trunk Stab Push Up III (male)***

III

• Males perform one repetition with thumbs aligned with the top of the forehead
• Females perform one repetition with thumbs aligned with chin

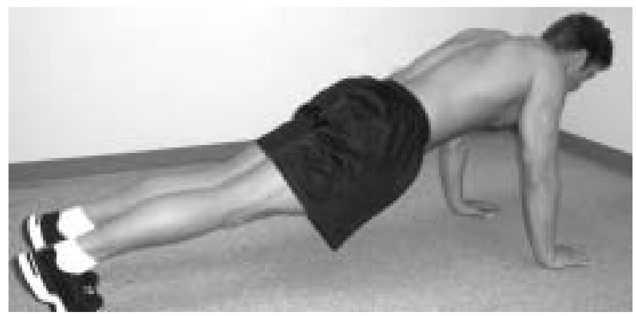

Figure 9. ***Trunk Stab Push Up II (male)***

II

• Males perform one repetition with thumbs aligned with chin
• Females perform one repetition with thumbs aligned with clavicle

Figure 10. ***Trunk Stab Push Up II (male)***

I

• Males are unable to perform one repetition with hands aligned with chin
• Females are unable to perform one repetition with thumbs aligned with clavicle

Clearing exam. A clearing exam is performed at the end of the trunk stability push-up test. This movement is not scored; the test is simply performed to observe a pain response. If pain is produced, a score of zero is given for the entire push-up test. This clearing exam is necessary because back pain can sometimes go undetected during movement screening.

Spinal extension can be cleared by performing a press-up in the push-up position *(Figure 11)*. If pain is associated with this motion, a zero is given and a more thorough evaluation should be performed.

Figure 11. ***Spinal Extension Clearing Test***

Clinical Implications for Trunk Stability Push-up

The ability to perform the trunk stability push-up requires symmetric trunk stability in the sagittal plane during a symmetric upper extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force symmetrically from the upper extremities to the lower extremities and vice versa. Movements such as rebounding in basketball, overhead blocking in volleyball, or pass blocking in football are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed and lead to poor functional performance, as well as increased potential for micro traumatic injury.

Poor performance during this test can be attributed simply to poor stability of the trunk stabilizers. When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using test by Kendall[6] or Richardson et al[8] for upper and lower abdominal and trunk strength. However, the test by Kendall[6] requires a concentric contraction while a push-up requires an isometric stabilizing reaction to avoid spinal hyperextension. A stabilizing contraction of the core musculature is more fundamental and appropriate than a simple strength test, which may isolate one or two key muscles. At this point, the muscular deficit should not necessarily be diagnosed. The screening exam simply implies poor trunk stability in the presence of a trunk extension force, and further examination at a later time is needed to formulate a diagnosis..

Rotary Stability

Purpose. The rotary stability test is a complex movement requiring proper neuromuscular coordination and energy transfer from one segment of the body to another through the torso. The rotary stability test assesses multi-plane trunk stability during a combined upper and lower extremity motion.

Description. The individual assumes the starting position in quadruped with their shoulders and hips at 90 degrees relative to the torso. The knees are positioned at 90 degrees and the ankles should remain dorsiflexed. The individual then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately 6 inches. The same shoulder is then extended and the knee flexed enough for the elbow and knee to touch. This is performed bilaterally for up to three repetitions. If a III is not attained then the individual performs a diagonal pattern using the opposite shoulder and hip in the same manner as described *(Figures 12-16).*

Tips for Testing:

- Scoring is identified by the upper extremity movement on the score sheet, but even if someone gets a three, both diagonal patterns must be performed and scored. The information should be noted
- Make sure the elbow and knee touch during the flexion part of the movement
- Provide cueing to let the individual know that he/she does not need to raise the hip and arm above 6 inches off of the floor
- When in doubt, score the subject low
- Do not try to interpret the score when testing

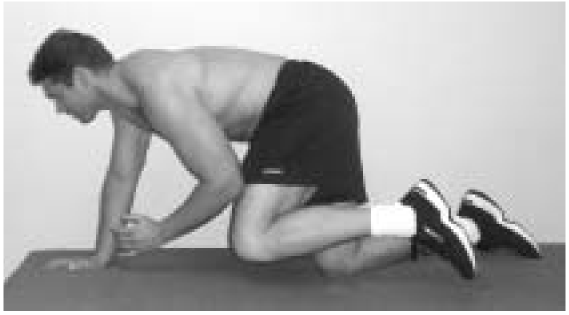

Figure 12. ***Rotary Stab Start III***

Figure 13. ***Rotary Stab Finish III***

III

- Performs one correct unilateral repetition while keeping spine parallel to surface
- Knee and elbow touch

Figure 14. ***Rotary Stab Start II***

Figure 15. ***Rotary Stab Finish II***

II

- Performs one correct diagonal repetition while keeping spine parallel to surface
- Knee and elbow touch

Figure 16. ***Rotary Stab Start I***

I

- Inability to perform diagonal repetitions

Clearing exam. A clearing exam is performed at the end of the rotary stability test. This movement is not scored it is simply performed to observe a pain response. If pain is produced, a score of zero is given to the entire rotary stability test. This clearing exam is necessary because back pain can sometimes go undetected by movement screening.

Spinal flexion can be cleared by first assuming a quadruped position and then rocking back and touching the buttocks to the heels and the chest to the thighs *(Figure 17)*. The hands should remain in front of the body reaching out as far as possible.

Figure 17. ***Spinal Flexion Clearing Test***

Clinical Implications for Rotary Stability
The ability to perform the rotary stability test requires asymmetric trunk stability in both sagittal and transverse planes during asymmetric upper and lower extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force asymmetrically from the lower extremities to the upper extremities and vice versa. Running and exploding out of a down stance in football and track are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed, leading to poor performance and increased potential for injury.

Poor performance during this test can be attributed simply to poor asymmetric stability of the trunk stabilizers. When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using Kendall's test for upper and lower abdominal strength.[6]

SUMMARY

The research related to movement-based assessments is extremely limited, mainly because only a few movement-based quantitative assessment tests are being utilized. According to Battie et al,[4] the ultimate test of any pre-employment or pre-placement screening technique is its effectiveness in identifying individuals at the highest risk of injury. If the FMS™, or any similarly developed test, can identify at risk individuals, then prevention strategies can be instituted based on their scores. A proactive, functional training approach that decreases injury through improved performance efficiency will enhance overall wellness and productivity in many active populations.

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ORIGINAL RESEARCH

THE LATERAL SCAPULAR SLIDE TEST: A RELIABILITY STUDY OF MALES WITH AND WITHOUT SHOULDER PATHOLOGY

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ABSTRACT

Background. Abnormal scapular movement or malposition is related to shoulder pathology. The lateral scapular slide test (LSST) is used to determine scapular position with the arm abducted in three positions.

Objective. The purpose of this study was to test the reliability of the LSST using a scoliometer.

Methods. Thirty-three male subjects (18 to 34 years) participated in this study. Group one (n = 15) had shoulder pathology; Group two (n = 18) did not have pathology. A test-retest, repeated measures design, with three experienced raters and the three positions of the LSST, was used to test the reliability of the LSST. All measurements in each position were taken bilaterally.

Results. Pearson Correlations for Position 1 and 2 ranged from .78 to .92 whereas position 3 ranged from .62 to .81. The ICC (2,2) ranged from .87 to .95 for positions 1 and 2. ICC (2,2) ranged from .70 to .82 for positions 3. Overall ICC (2,3) ranged from .83 to .96. The coefficients of determination ranged from .38 to .89. The SEM ranged from 3.00 to 8.26 mm, with the largest error found in position 3.

Discussion and Conclusion. The LSST can be reliable in screening scapular position. Although a large range of error exists in measurements as indicated by the standard error of the measurement, the LSST provides more objective measures than pure observation.

Key Words: scapula, shoulder, measurement.

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INTRODUCTION

Orthopedic clinicians frequently evaluate and provide therapeutic intervention for shoulder dysfunction. A very important link in shoulder function, the scapula merits special attention. The functional role of the scapula is often misunderstood by clinicians, and this lack of awareness can result in incomplete evaluation and diagnosis of impairment of the shoulder.[1,2] Consequently, scapular rehabilitation is often ignored.[3-5]

Most authors consider the assessment of scapular positioning on the thoracic cage to be part of a comprehensive evaluation of patients with suspected shoulder dysfunction.[6–8] Restricted scapulohumeral motion may lead directly to rotator cuff impingement and an eventual partial or full-thickness tear of the rotator cuff tendons.[7,9,10] Observing the scapulothoracic rhythm is necessary because disruption to this movement may lead to dysfunction.[3,6,7,10-12]

Kibler[1,4] described a test to clinically measure static scapular positions called the lateral scapular slide test (LSST). This test involves measuring the distance from the inferior angle of the scapula to the nearest vertebral spinous process using a tape measure or goniometer in three positions: shoulder in neutral, shoulder at 40-45 degrees of coronal plane abduction with hands resting on hips, and the shoulder at 90 degrees abduction with the arms in full internal rotation. Kibler[1,4] contends that the injured or deficient side would exhibit a greater scapular distance than the uninjured or normal side and asserted that a bilateral difference of 1.5 cm (15 mm) should be the threshold for deciding whether scapular asymmetry is present. Kibler[1] also suggested that the LSST may be used to monitor the scapular stabilizer muscles in any rehabilitative program that involves shoulder strengthening exercises. Inferences drawn by Kibler[1] about scapular symmetry and shoulder pathology are based largely on unpublished work and most of his data collection is performed with overhead throwing athletes.

Several researchers determined that the LSST measurements may be too variable and, thus, unreliable to be useful.[7,13-15] However, T'Jonck et al[16] concluded that the LSST technique holds promise for further studies, has the advantage of measuring in three positions, and with some familiarization can be reliable.

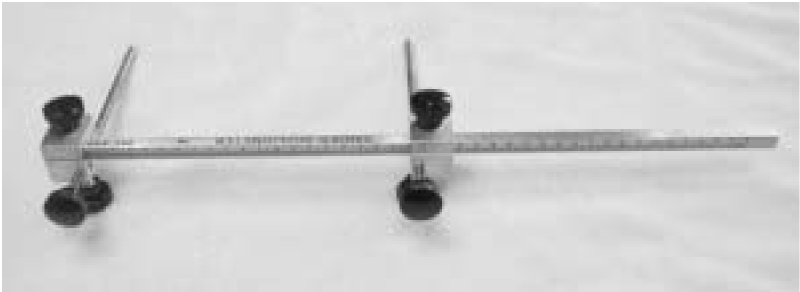

Figure 1. Scoliometer used in data collection that had been machined tooled to allow measurement data to the nearest millimeter.

The purpose of this study was to determine the reliability of the LSST and its error between raters using a scoliometer. A scoliometer similar to the one used in the present study has shown high reliability and moderate validity to detect scoliosis.[17,18] Since the scoliometer has been shown to be a simple and reliable tool in detecting scoliosis, the present study extended its use to measure scapular position.

Figure 2. Test position 1 standing in dependent position.

METHODS

Subjects

Thirty-three volunteer subjects were recruited from the Phoenix, Arizona metropolitan area. Subjects were males ranging in age from 18 to 34 years (mean = 25.5; SD = 5.69). Eighteen of the subjects reported no shoulder pain, injury, or history of dysfunction. Fifteen of the subjects reported diagnoses of unilateral or bilateral shoulder pathology or injury. Diagnoses included tendonitis/strain (6), impingement (3), acromioclavicular separation (3), clavicle fracture (2), and dislocation (1). Diagnoses of injury were made before inclusion of all subjects in the study. These diagnoses were self-reported by the subject following examination by a physician. Exclusion criteria included systemic disease that affects neuromuscular function, the inability to maintain at least 90 degrees of bilateral coronal plane shoulder abduction, existence of any observed postural or bony deformities regardless of physician's diagnosis, or any existing medical diagnosis prohibiting the subject from participating in the study.

Equipment

A scoliometer (Dr. Sabia's Scoliometer, Red Bank, NJ), marked in millimeters, was used in this study to measure the linear scapular distances. A scoliometer can be described as a caliper attached to two movable points as shown in *Figure 1*. Amendt et al[17] found high intrarater and interrater reliability (r = .86 - .97) using the scoliometer in detecting scoliosis. Amendt et al[17] also determined the validity of the scoliometer compared to x-ray and reported correlation coefficients between .32 and .46. Interrater reliability ranged from .81 - .82 in a different study by Murrell et al.[18]

Examiners

Three physical therapists, employed within a separate private practice setting, administered the LSST to the subjects. The three therapists averaged 22.67 years of experience (SD = 2.52), predominantly in an orthopedic practice setting. All raters were experienced in using the LSST, but were not familiar with the scoliometer.

Data Collection

Prior to data collection, each evaluating therapist participated in a session to discuss the purpose of the study, as well as the inclusion and exclusion criteria of the subjects. Each therapist was then individually trained in the measurement procedure by the primary investigator, including written and verbal instructions for evaluating the subject, appropriate standing postures, and appropriate positioning of the shoulder in the three test positions. The evaluating therapist practiced the procedure until he/she felt sufficiently competent and comfortable with the measurement tool and procedures.

The Institutional Review Board (IRB) of Rocky Mountain University of Health Sciences approved this study as safe for human subjects. All subjects participating in this study were required to read and sign an informed consent agreement before any participation in this study. Subjects were asked to complete brief, self-reported medical history. Subjects with and without pathologies participated in this study, but the evaluating therapist/raters did not have knowledge of the subjects' medical histories.

Figure 3. Test position 2 with arms resting on hips with thumbs posterior.

The subject was then instructed to assume the first test position of the LSST with the shoulders in neutral position *(Figure 2)*. Using the scoliometer, each therapist measured the distance between the inferior angle of the scapula and the closest thoracic spinous process in the first test position. The therapist then locked the knobs of the scoliometer to assure that the caliper was fixed. The scoliometer was then handed to the primary investigator, who silently read and recorded the measures. The scoliometer was then reset to zero and the therapist repeated this procedure a second time. An average of the two readings was used for data analysis. This process was repeated on the right and left sides. The first therapist then exited and the second therapist entered the room and immediately applied the scoliometer in the same fashion as the previous therapist with the subject. This same procedure was followed by the third therapist. After each therapist measured each subject in the first test position, the procedures were repeated for the second test position *(Figure 3)*; hands resting on hips with thumbs posterior.

Figure 4. Test position 3 with arms abducted 90 degrees with full shoulder internal rotation.

The third test position required the subject to maintain a posture of approximately 90 degrees of shoulder abduction, full shoulder internal rotation, and full radioulnar supination *(Figure 4)*. This movement was difficult for some subjects. Therefore, the subjects were allowed to return to the first test position after each evaluating therapist completed his series of measurements in the third test position. Before the subsequent evaluating therapist obtained their measures, the subject was instructed to return to the third test position. The subjects were not allowed to change their standing posture. Upon completion of the series of scoliometer measurements in each of the subsequent test positions by the evaluating therapist, the subject was then excused and the process was repeated with the next subject. The therapists were also unaware of any of their measurements, nor those of the other evaluators. All measurements were determined consecutively from position 1 to position 3 and bilaterally.

Data Analysis

Pearson correlation coefficients were calculated to determine the relationships between measures. When determining the relationship between the two sets of variables, Domholdt[19] described terminology about the strength of the relationships. A correlation of .90 to 1.00 was described as a very high relationship; whereas a correlation of .70 to .89 was described as a high relationship. A correlation of .50 to .69 was described as a moderate relationship and a correlation of .26 to .49 was described as a low relationship. However, a correlation of .00 to .25 was indicative of little, if any, relationship.

In addition, coefficients of determination were calculated to determine the shared variability between measures for the three therapists. This coefficient is an indication of the proportion or percentage of variance between two variables. A coefficient of determination of 50% or more is considered good.[19]

In addition, standard errors of the measurement (SEM) were calculated to determine the amount of error between the therapists. The SEM, as a measure of absolute reliability and the standard deviation of measurement error, can be an estimate of how much a score varies between raters for repeated measures.

Finally, to determine the agreement between the therapists, an intraclass correlation coefficient (ICC) was calculated, using models ICC (2,2) and ICC (2,3). All statistical calculations were performed using the Statview statistical package (SAS, Cary, NC).

Table 1. Correlation coefficients (r), coefficient of determination (r^2), intraclass correlation coefficients (ICC), and standard error of the measurements (SEM) between the three raters for the subjects without pathology.

Rater	Position	r *	r^2	ICC (2,2)	SEM**
1 vs. 2	One	.92	.85	.94	5.21
1 vs. 3	One	.91	.83	.95	5.58
2 vs. 3	One	.92	.85	.95	4.80
1 vs. 2	Two	.82	.67	.87	6.37
1 vs. 3	Two	.80	.64	.87	7.16
2 vs. 3	Two	.92	.85	.96	4.38
1 vs. 2	Three	.66	.44	.77	7.54
1 vs. 3	Three	.64	.41	.75	8.26
2 vs. 3	Three	.81	.66	.77	6.22

*All correlations were significant at an alpha level of .05
**SEM measured in mm

RESULTS

In the group of subjects without pathology, a very high relationship existed between raters for test position 1 and test position 2 *(Table 1)*. For test position 3, a moderate to high relationship existed. In the group of subjects with pathology, again, a very high relationship was found between raters for test position 1 and test position 2 *(Table 2)*. For test position 3, a moderate relationship existed as the coefficients ranged between .62 and .72. Although a strong relationship occurred and less error (as indicated by the coefficient of determination) with test positions 1 and 2 in subjects with and without shoulder pathology, less relationship and shared variability was found in test position 3.

When comparing the SEM with the threshold of 15 mm proposed by Kibler,[1] these coefficients were quite low, as found in Tables 1 and 2. For position 3 in both groups, the SEMs are less than the threshold of 15 mm, but are 50% of the threshold. This finding may be of some concern in that most of the measure to the threshold may be error.

Intraclass correlation coefficients (ICC), specifically an ICC (2,2) and ICC (2,3), were performed to determine the agreement between raters. Using an ICC (2,2), the agreement between raters for subjects without pathology and with pathology was considered good for position 1 and position 2. For position 3, the agreement was considered moderate to good for subjects without pathology and with pathology. The overall agreement between the three raters for subjects with and without pathology, using an ICC (2,3), was found to be good *(Table 3)*. The ICC (2,3) for all the test positions of both involved and noninvolved shoulder groups had demonstrated a strong degree of agreement, thus, demonstrating high interrater reliability.

DISCUSSION

Kibler[1,21] proposed that assessment of scapular symmetry is based on biomechanics and believed that muscle deficiencies are associated with an unstable scapula. Although a thorough understanding of shoulder girdle mechanics is important, the reliability of the LSST remains in question. Results of previous reliability studies of scapular positioning, as well as those presented in this article, have demonstrated that measurements of linear distance related to the scapula can be reliable.[12,22,23] The LSST has been used to assess scapular asymmetry, which may be indicative of shoulder dysfunction. Moreover, the LSST is a relatively simple procedure that is neither time intensive nor expensive. However, while some researchers have found the LSST to be reliable,[24,25] many researchers concluded the LSST may be too variable and, thus, unreliable.[7,12-14,26]

Using the ICC, good reliability appears to exist for using the LSST for test positions 1, 2, and 3 for subjects without pathology. For subjects with pathology, the reliability of test positions 1 and 2 would appear to be good; but for test position 3, the reliability would appear to be moderate to good. Test position 3 challenges scapular stability by abduction and internal rotation of the humerus at 90 degrees and closely approximating the humeral head against the coracoacromial hood. The scapular stabilizers, particularly the serratus anterior, are forced to contract and upwardly rotate the scapula to prevent impingement of suprahumeral structures. Thus, test position 3 challenges the muscular force couple and, therefore, one may see more variability with scapular positioning. While maintaining position 3, impingement of pain sensitive structures may occur, thus, increasing the variability of the measures.

Table 2. Correlation coefficients (r), coefficient of determination (r^2), intraclass correlation coefficients (ICC), and standard error of the measurements (SEM) between the three raters for the subjects with pathology.

Rater	Position	r *	r^2	ICC (2,2)	SEM**
1 vs. 2	One	.88	.77	.93	4.60
1 vs. 3	One	.87	.76	.91	4.76
2 vs. 3	One	.95	.89	.97	3.00
1 vs. 2	Two	.78	.61	.87	5.38
1 vs. 3	Two	.81	.66	.88	4.72
2 vs. 3	Two	.87	.76	.93	4.18
1 vs. 2	Three	.69	.48	.80	6.86
1 vs. 3	Three	.72	.52	.82	6.36
2 vs. 3	Three	.62	.38	.70	7.20

*All correlations were significant at an alpha level of .05
**SEM measured in mm

Kibler[1,4] has asserted that a bilateral difference of 1.5 cm (or 15 mm) should be the threshold for deciding whether scapular asymmetry is present. As stated previously, the SEM for subjects without pathology ranged between 4.80 mm and 5.58 mm for position 1, between 4.38 mm and 7.16 mm for position 2, and between 6.22 mm and 8.26 mm for position 3. Portney and Watkins[20] stated that the SEM can be used as an estimate of reliability, in that there is a 95% chance that the true mean score lies within a range of ± 2 SEM. For the SEM reported in this study, these ranges would be quite large. Therefore, while the relationships and agreement of the scores (as indicated with the Pearson Correlation Coefficients and ICC's) were quite high and would be indicative of high reliability, the true score for the LSST may be greater than the 1.5 cm asserted by Kibler.[1] Therefore, the threshold of 1.5 cm to be considered shoulder asymmetry needs further scrutiny.

Table 3. ICC (2,3) for an overall agreement between the raters for the three test positions and for the subjects with and without pathology.

Subjects without pathology		Subjects with pathology	
Position	ICC (2,3)	Position	ICC (2,3)
One	0.96	One	0.96
Two	0.93	Two	0.93
Three	0.83	Three	0.84

Odom et al[13] found that comparing the LSST between the two scapulae was unreliable and, thus, deduced the LSST to be invalid and unreliable. They used a simple measurement procedure using a string to determine the linear measurement, whereas a scoliometer was used in this study. They acknowledged the differences in measurement technique and clinical experience among raters might partially account for their findings. Problems with the tensile properties of string may have existed, which was not taken into consideration in the Odom et al[13] study and may have created significant intra and interrater variance.

A major difference in this study compared to Odom et al[13] was the experience of the raters. Odom et al[13] used six raters with an average of 5.8 years of experience. They felt this reflected the experience of a clinician in an outpatient orthopedic setting. The experience of the raters in this study averaged over 22 years. All of the raters in the study were familiar with the LSST, but were not familiar with the scoliometer. Using a scoliometer for measurement was an attempt to further provide objective measures. Perhaps by using a scoliometer, physical therapy students or novice physical therapists may be more reliable in measuring LSST.

Numerous investigators have been critical of 2-dimensional methods for scapular assessment.[2,7,15] Methods using 2-dimensional analysis do not assess the tipping or tilting of the scapula about an axis parallel to the scapular spine and winging of the scapula about a vertical axis.[27,28] However, many clinicians are forced to assess shoulder and scapular motion with 2-dimensional methods. Furthermore, practical assessment using 3-dimensional methods remains conjecture at best, due to expense, time, and availability. It is not known if 3-dimensional methods would provide more information to the clinician in developing a plan of care for the patient or client.

Several limitations existed in this study. The investigator could not control the educational background of the rater/therapist. Although subjects with shoulder pathology were included in the sample, the investigator did not control the type of pathology the subject presented nor the functional range of motion presented by the subject. However, it should be noted that the validity of LSST is based on its face validity compared to clinical observation of scapular asymmetry. The raters in this study, due to their clinical experience, were assumed to use very accurate visualization, palpation, and measurement skills of the inferior angle of the scapula and the adjacent thoracic spinous process. Still, the raters in this study all reported greater difficulty evaluating mesomorphic males due to muscle mass and adipose tissue, which may obscure the identification of anatomical landmarks. Because the raters were unaware of either their own measurements or those of the other raters, the results are not likely to have been influenced by bias.

CONCLUSIONS

The results of our investigation were that measurements obtained with the lateral scapular slide test (LSST) and a scoliometer are reliable in assessing scapular positioning or symmetry. However, a large range of error in measurements was found as indicated by the SEM, when to the parameters proposed by Kibler.[1] The parameter of 1.5 cm (15 mm) as an indicator of shoulder dysfunction should be further scrutinized. The authors believe the LSST provides more objective measures than pure observation and can be enhanced by using a scoliometer or caliper rather than a tape measure.

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