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Rehabilitation After Anterior Cruciate Ligament Reconstruction in the Female Athlete

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Objective: To discuss the rehabilitation program after ante- ·ior cruciate ligament (ACL) reconstruction in the female athlete. n addition, we will discuss 8 unique characteristics identified in :he female athlete and specific training drills to address and :orrect the potentially deleterious effects of these unique :haracteristics.

Background: The female athlete appears to be more sus- :eptible to noncontact ACL injuries than the male athlete. There ;eem to be many differences between the female and male ıthlete that may contribute to the increased injury rate in the emale athlete. These variations include anatomical and neuro- nuscular considerations and differences.

Description: Based on the unique characteristics of the emale athlete and the anatomical and neuromuscular dissimilarities, a specially designed rehabilitation program has been established for the female athlete after ACL surgery.

Clinical Advantages: The rehabilitation drills discussed in this article challenge the neuromuscular system through proprioception, kinesthesia, dynamic joint stability, neuromuscular control, and perturbation training activities. Improving the female athlete's neuromuscular system will, we believe, expedite the injured athlete's recovery after ACL injury or surgery. Although the concepts discussed are part of a postoperative rehabilitation program after ACL surgery, these concepts may also be implemented as a preventive program to assist in reducing the incidence of ACL injuries in the female athlete.

Key Words: neuromuscular control, perturbation training, dynamic stability

Anterior cruciate ligament (ACL) injuries are the most common severe ligamentous injuries incurred by athletes. The typical mechanism of injury is deceleration ·ith twisting, pivoting, or a change of direction. In our clinical :xperience, at least 60% of all ACL injuries sustained by :hletes are due to a noncontact mechanism of injury. The :male athlete appears to be more susceptible to noncontact CL injuries than her male counterpart.[1–5]

An increasing number of female athletes seem to be sustain- g ACL injuries. Malone et al[1] reported that collegiate female ısketball players were 8 times more likely to sustain ACL juries compared with collegiate male basketball players. uring the 1989–1990 intercollegiate basketball season, the CAA Injury Surveillance System reported that female ath- :es injured their ACLs 7 to 8 times more frequently than male ıletes.[2] Lindenfeld et al[3] reported that the injury rate for ACL juries in female soccer players was 6 times greater than that male soccer players. Other sports in which the female athlete pears to be more susceptible to ACL injuries include lleyball and gymnastics.[4,5] Ferretti et al[4] reported a 4-fold gher incidence of serious knee ligament injuries in female versus male elite volleyball players. Chandy and Grana,[5] in a 3-year study, reported that female athletes were 4.6 times more likely to sustain a season-ending knee injury than male athletes. Specifically, female athletes in jumping sports had significantly more severe knee injuries.

Understanding the reasons for this increased injury rate is vital to the development of a postoperative rehabilitation program, and even more importantly, a preventive training program to decrease the incidence of severe ligamentous injury. According to our injury data, including high school and college athletes in all competitive and recreational sports, the female high school athlete appears to have a 1 in 100 chance of sustaining an ACL injury, whereas the male high school athlete appears to have a 1 in 500 chance of sustaining an ACL injury. The collegiate male athlete appears to exhibit a 1 in 50 chance, while the collegiate female athlete appears to have a 1 in 10 chance (K. E. Wilk et al, unpublished data, 1998).

Thus, with the increasing number of females participating in athletics and an increasing number of ACL injuries occurring, a specific postoperative rehabilitation program for the female athlete after ACL surgery is useful. In this article, we will discuss the rehabilitation program after ACL surgery. Additionally, specific exercises to address the unique characteristics

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The Relationship Between Subjective Knee Scores, Isokinetic Testing, and Functional Testing in the ACL-Reconstructed Knee[1]

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It is important to examine the functional relationships between commonly performed clinical tests and to resolve inconsistencies in previous investigative results. The purpose of this study was to determine if a correlation exists between three commonly performed clinical tests: isokinetic isolated knee concentric muscular testing, the single-leg hop test, and the subjective knee score in anterior cruciate ligament reconstructed knees. To determine if a relationship exists would be beneficial to clinicians in determining patient progression, treatment modification, and return-to-sport objective parameters. Several investigators have analyzed two of these parameters, but no one has investigated three parameters to date. Additionally, this study explored the concept of limb acceleration and deceleration during high-speed isokinetics and its relationship to function. Fifty patients were randomly selected (29 males) with a mean age of 23.7 years (range 15–52). The subjects completed a subjective knee score questionnaire that rated symptoms (pain, swelling, giving way) and specific sport function and completed an overall knee score assessment. The patients were then evaluated performing three one-legged functional tests: 1) hop for distance, 2) timed hop, and 3) cross-over triple hop. Isokinetic testing was performed on a Biodex dynamometer at 180, 300, and 450°/sec for knee extension/flexion. The patients' mean value of the self-assessed knee rating was 86 points. Sixty-four percent of the patients exhibited normal limb symmetry (within 85%) on all three single-leg hop tests. Sixteen percent exhibited quadriceps strength at least 90% of the contralateral limb isokinetically. A positive correlation was noted between isokinetic knee extension peak torque (180, 300°/sec) and subjective knee scores, and the three hop tests ($p < 0.001$). A statistical trend was noted between knee extension acceleration and deceleration range at 180 and 300°/sec for the timed hop test and triple cross-over hop ($r = 0.48$, $r = 0.49$, $r = 0.51$, $r = 0.49$). No positive correlations were found for isokinetic test results for the knee flexors.

Key Words: *knee joint stability, anterior cruciate ligament, muscle strength, functional testing*

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Isokinetic testing is a commonly utilized tool for the assessment of muscular strength in the orthopaedic and sports medicine setting. Isokinetics are frequently chosen because of their inherent patient safety (21), objectivity (108,115), and reproducibility in testing measures (28,64,113). Most often, the interpretation of isokinetic test data has been limited to the assessment of peak torque (1,9,14,19,30,31,40,45,46,49,50,51,65,70,72,81,84,95). Numerous authors have documented clinical outcome studies utilizing peak torque parameters, especially the bilateral comparison ratio of the quadriceps and hamstring muscles' peak torque measurements (10,27,32,37,38,42,52,58,62,63,66,75,85,88,89,94,103,104). A few investigators have reported outcomes utilizing muscular performance parameters such as work, power, and endurance (25,26,43,44,47,99,112,114). Limiting data analysis solely to peak torque and work parameters has stymied the development of isokinetic test data interpretation for other test parameters such as acceleration and deceleration rates during knee movements (109).

Human movements, especially sports movements, utilize a series of

Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises

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ABSTRACT

ESCAMILLA, R. F., G. S. FLEISIG, N. ZHENG, S. W. BARRENTINE, K. E. WILK, and J. R. ANDREWS. Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Med.Sci. Sports Exerc.*, Vol.30, No. 4, pp. 556–569, 1998. **Purpose:** Although closed (CKCE) and open (OKCE) kinetic chain exercises are used in athletic training and clinical environments, few studies have compared knee joint biomechanics while these exercises are performed dynamically. The purpose of this study was to quantify knee forces and muscle activity in CKCE (squat and leg press) and OKCE (knee extension). **Methods:** Ten male subjects performed three repetitions of each exercise at their 12-repetition maximum. Kinematic, kinetic, and electromyographic data were calculated using video cameras (60 Hz), force transducers (960 Hz), and EMG (960 Hz). Mathematical muscle modeling and optimization techniques were employed to estimate internal muscle forces. **Results:** Overall, the squat generated approximately twice as much hamstring activity as the leg press and knee extensions. Quadriceps muscle activity was greatest in CKCE when the knee was near full flexion and in OKCE when the knee was near full extension. OKCE produced more rectus femoris activity while CKCE produced more vasti muscle activity. Tibiofemoral compressive force was greatest in CKCE near full flexion and in OKCE near full extension. Peak tension in the posterior cruciate ligament was approximately twice as great in CKCE, and increased with knee flexion. Tension in the anterior cruciate ligament was present only in OKCE, and occurred near full extension. Patellofemoral compressive force was greatest in CKCE near full flexion and in the mid-range of the knee extending phase in OKCE. **Conclusion:** An understanding of these results can help in choosing appropriate exercises for rehabilitation and training. **Key Words:** CLOSED KINETIC CHAIN, OPEN KINETIC CHAIN, MUSCLE ACTIVITY, PCL, ACL, PATELLOFEMORAL, TIBIOFEMORAL, JOINT FORCE

In 1955, Steindler (54) defined two types of exercises: closed kinetic chain exercises (CKCE) and open kinetic chain exercises (OKCE). In a CKCE, the terminal or distal segment is opposed by "considerable resistance"; in a OKCE, the distal segment is free to move without any external resistance. If the external resistance is fixed from moving, the system is "strictly and absolutely closed." These categories are often found to be inaccurate or confusing (44). To reduce confusion, Dillman et al. (16) proposed three categories of exercises: a fixed boundary condition with an external load (e.g., leg press where seat slides and the foot plate is fixed), a movable boundary with an external load (e.g., leg press where the seat is fixed and the foot plate moves), and a movable boundary with no external load. In this study CKCE of the leg are defined as exercises in which the feet are fixed from moving and OKCE of the leg are those with no external resistance for movement of the feet.

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CKCE—such as squat, leg press, deadlift, and power-clean—have long been used as core exercises by athletes to enhance performance in sport. (11,27) These multi-joint exercises develop the largest and most powerful muscles of the body and have biomechanical and neuromuscular similarities to many athletic movements, such as running and jumping. Recently CKCE have been used and recommended in clinical environments, such as during knee rehabilitation following anterior cruciate ligament (ACL) reconstruction surgery (22,33,38,43,44,50,67,68).

It is difficult to compare tibiofemoral compressive forces during the squat between various published studies since some studies modeled both external forces (e.g., gravity, ground reaction, inertia) and internal forces (e.g., muscle, bone, ligament) (3,13,36,42), while others modeled only external forces (1,20,58). Furthermore, only three of these studies specified the direction of the tibiofemoral shear force (36,41,58), making it difficult to determine which cruciate ligament was loaded. All three of these studies found moderate posterior cruciate ligament (PCL) tensile forces at higher knee angles (0° = full knee extension) and minimum ACL forces at smaller knee angles. Exact knee angles were stated in only one of these studies (58). Only one known study quantified patellofemoral compressive forces during the squat exercise (46). However, the squats in

Effects of technique variations on knee biomechanics during the squat and leg press

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ABSTRACT

ESCAMILLA, R. F., G. S. FLEISIG, N. ZHENG, J. E. LANDER, S. W. BARRENTINE, J. R. ANDREWS, B. W. BERGEMANN, and C. T. MOORMAN, III. Effects of technique variations on knee biomechanics during the squat and leg press. *Med. Sci. Sports Exerc.*, Vol. 33, No. 9, 2001, pp. 1552–1566. **Purpose:** The specific aim of this project was to quantify knee forces and muscle activity while performing squat and leg press exercises with technique variations. **Methods:** Ten experienced male lifters performed the squat, a high foot placement leg press (LPH), and a low foot placement leg press (LPL) employing a wide stance (WS), narrow stance (NS), and two foot angle positions (feet straight and feet turned out 30°). **Results:** No differences were found in muscle activity or knee forces between foot angle variations. The squat generated greater quadriceps and hamstrings activity than the LPH and LPL, the WS-LPH generated greater hamstrings activity than the NS-LPH, whereas the NS squat produced greater gastrocnemius activity than the WS squat. No ACL forces were produced for any exercise variation. Tibiofemoral (TF) compressive forces, PCL tensile forces, and patellofemoral (PF) compressive forces were generally greater in the squat than the LPH and LPL, and there were no differences in knee forces between the LPH and LPL. For all exercises, the WS generated greater PCL tensile forces than the NS, the NS produced greater TF and PF compressive forces than the WS during the LPH and LPL, whereas the WS generated greater TF and PF compressive forces than the NS during the squat. For all exercises, muscle activity and knee forces were generally greater in the knee extending phase than the knee flexing phase. **Conclusions:** The greater muscle activity and knee forces in the squat compared with the LPL and LPH implies the squat may be more effective in muscle development but should be used cautiously in those with PCL and PF disorders, especially at greater knee flexion angles. Because all forces increased with knee flexion, training within the functional 0–50° range may be efficacious for those whose goal is to minimize knee forces. The lack of ACL forces implies that all exercises may be effective during ACL rehabilitation. **Key Words:** POWERLIFTING, KINETICS, PATELLOFEMORAL, TIBIOFEMORAL, ACL, PCL, COMPRESSIVE, SHEAR, REHABILITATION, FORCE, MUSCLE ACTIVITY, EMG

The dynamic squat and leg press (LP) exercises are common core exercises that are utilized by athletes to enhance performance in sport. These multi-joint exercises develop the largest and most powerful muscles of the body and have biomechanical and neuromuscular similarities to many athletic movements, such as running and jumping. Because the squat and LP are considered closed kinetic chain exercises (11,34), they are often recommended and utilized in clinical environments, such as during knee rehabilitation after anterior cruciate ligament (ACL) reconstruction surgery (17,23). Athletes and rehabilitation patients perform the squat and LP exercises with varying techniques according to their training or rehabilitation protocols. An athlete or patient with patellar chondromalacia, or recovering from ACL reconstruction, may prefer a squat or LP technique that minimizes patellofemoral compressive force or tibiofemoral anterior shear force. Athletes or patients typically choose a squat or LP technique according to personal preference and effectiveness. Furthermore, athletes often use varying techniques to develop specific muscles. Some prefer training the squat and LP with a narrow stance, whereas others prefer a wide stance. Similarly, some athletes prefer their feet pointing straight ahead, whereas others prefer their feet slightly turned out. In addition, some athletes prefer a high foot placement on the LP foot plate, whereas others prefer a low foot placement. However, the effects that these varying stances, foot angles, and foot placements have on knee forces and muscle activity is currently unknown.

During performance of the dynamic squat exercise, several studies have quantified tibiofemoral compressive forces (4,9,11,12,21,30,34), tibiofemoral shear forces (3,4, 9,11,12,21,30,32,34), patellofemoral compressive forces (9,11,21,25,35), and muscle activity about the knee (9,11, 15,19,20,26,27,30,34–37). There are two known studies that have quantified tibiofemoral forces, patellofemoral forces, and muscle activity during the dynamic LP (11,34). However, none of these squat or LP studies quantified knee forces while performing these exercises. Although there are a few studies that quantified muscle activity while performing the squat with varying foot positions (7,19,20,26,31),

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A Comparison of Tibiofemoral Joint Forces and Electromyographic Activity During Open and Closed Kinetic Chain Exercises*

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ABSTRACT

We chose to investigate tibiofemoral joint kinetics (compressive force, anteroposterior shear force, and extension torque) and electromyographic activity of the quadriceps, hamstring, and gastrocnemius muscles during open kinetic chain knee extension and closed kinetic chain leg press and squat. Ten uninjured male subjects performed 4 isotonic repetitions with a 12 repetition maximal weight for each exercise. Tibiofemoral forces were calculated using electromyographic, kinematic, and kinetic data. During the squat, the maximal compressive force was 6139 ± 1708 N, occurring at 91° of knee flexion; whereas the maximal compressive force for the knee extension exercise was 4598 ± 2546 N (at 90° knee flexion). During the closed kinetic chain exercises, a posterior shear force (posterior cruciate ligament stress) occurred throughout the range of motion, with the peak occurring from 85° to 105° of knee flexion. An anterior shear force (anterior cruciate ligament stress) was noted during open kinetic chain knee extension from 40° to full extension; a peak force of 248 ± 259 N was noted at 14° of knee flexion. Electromyographic data indicated greater hamstring and quadriceps muscle co-contraction during the squat compared with the other two exercises. During the leg press, the quadriceps muscle electromyographic activity was approximately 39% to 52% of maximal velocity isometric contraction; whereas hamstring muscle activity was minimal (12% maximal velocity isometric contraction). This study demonstrated significant differences in tibiofemoral forces and muscle activity between the two closed kinetic chain exercises, and between the open and closed kinetic chain exercises.

The clinical use of closed kinetic chain exercise has significantly increased during the past several years. One of the reasons closed kinetic chain exercises have received increased attention within the rehabilitation community is that they simulate and replicate many functional movements, such as squatting, stooping, and ascending or descending stairs. Additionally, it has been suggested that closed kinetic chain exercises are safer than open kinetic chain exercises because the former minimizes anteroposterior tibiofemoral shear forces and thus reduces stress on both the ACL and PCL. Closed kinetic chain exercises have been strongly recommended as the best form of exercise for the ACL-reconstructed knee.[8,10,17,29,30]

Terminology used for kinetic chain exercises was originally used to describe linkage analysis in mechanical engineering. Steindler,[34] in 1955, suggested that the human body could be thought of as a chain consisting of rigid overlapping segments of limbs connected by a series of joints. He observed that when the foot or hand meets considerable resistance, muscular recruitment and joint motion occurred differently from that seen when the foot or hand was free to move without restriction. Thus, closed kinetic chain exercise occurs when the terminal or distal segment of an appendage is fixed, such as during a squat, leg press, or pull up.[26] Conversely, open kinetic chain exercise occurs when the terminal or distal segment is free to move, such as during a knee extension or flexion maneuver.[26]

With these concepts firmly established, numerous clinicians have formulated exercise drills and techniques to use the closed kinetic chain exercise concept during rehabilitation of the knee.[12,17,22,28,36,39] Palmitier et al.[26] have documented that during closed kinetic chain exer-

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Current Concepts in the Rehabilitation Following Articular Cartilage Repair Procedures in the Knee

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Postoperative rehabilitation programs following articular cartilage repair procedures will vary greatly among patients and need to be individualized based on the nature of the lesion, the unique characteristics of the patient, and the type and detail of each surgical procedure. These programs are based on knowledge of the basic science, anatomy, and biomechanics of articular cartilage as well as the biological course of healing following surgery. The goal is to restore full function in each patient as quickly as possible by facilitating a healing response without overloading the healing articular cartilage. The purpose of this paper is to overview the principles of rehabilitation following articular cartilage repair procedures. Furthermore, specific rehabilitation guidelines for debridement, abrasion chondroplasty, microfracture, osteochondral autograft transplantation, and autologous chondrocyte implantation will be presented based upon our current understanding of the biological healing response postoperatively. *J Orthop Sports Phys Ther 2006;36(10):774-794.* doi:10.2519/jospt.2006.2228

Key Words: *autologous chondrocyte implantation, chondroplasty, microfracture, osteochondral autograft transplantation*

Articular cartilage defects of the knee are a common cause of pain and functional disability in orthopedics and sports medicine. The avascular nature of articular cartilage predisposes the individual to progressive symptoms and degeneration due to the extremely slow and often times inability of the cartilage to heal.[6-10] Nonoperative rehabilitation and palliative care are frequently unsuccessful, and further treatment is required to alleviate symptoms. This presents a significant challenge for patients, particularly young and more active individuals, that present without gross degenerative changes but rather focal cartilage defects. Traditional methods of treatment, such as nonoperative treatment and lavage, have led to unfavorable results,[29,35,52] stimulating the need for newer surgical procedures designed to facilitate the repair or transplantation of autogenous cartilage tissue.

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Postoperative rehabilitation programs will vary greatly among patients and are individualized based on the characteristics of the lesion, patient, and surgery. Thus, the development of an appropriate rehabilitation program is challenging and must be highly individualized to assure successful outcomes. These programs are designed based upon knowledge of the basic science, anatomy, and biomechanics of articular cartilage, as well as the biological course of healing following surgery. The goal is to restore full function in each patient as quickly as possible without overloading the healing articular cartilage.

In this paper we will discuss the principles of rehabilitation following articular cartilage repair procedures, as well as specific rehabilitation guidelines for debridement, abrasion chondroplasty, microfracture, osteochondral autograft transplantation (OATS), and autologous chondrocyte implantation (ACI).

PRINCIPLES OF ARTICULAR CARTILAGE REHABILITATION

Several principles exist that must be considered when designing a rehabilitation program following articular cartilage repair proce-

Rehabilitation of Articular Lesions in the Athlete's Knee

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CLINICAL COMMENTARY

Articular cartilage lesions of the knee joint are common in patients of varying ages. Some articular cartilage lesions are focal lesions located on one aspect of the tibiofemoral or patellofemoral joint. Other lesions can be extremely large or involve multiple compartments of the knee joint and these are often referred to as osteoarthritis. There are numerous potential causes for the development of articular cartilage lesions: joint injury (trauma), biomechanics, genetics, activities, and biochemistry. Numerous factors also contribute to symptomatic episodes resulting from lesions to the articular cartilage: activities (sports and work), joint alignment, joint laxity, muscular weakness, genetics, dietary intake, and body mass index. Athletes appear to be more susceptible to developing articular cartilage lesions than other individuals. This is especially true with specific sports and subsequent to specific types of knee injuries. Injuries to the anterior cruciate ligament and/or menisci may increase the risk of developing an articular cartilage lesion. The treatment for an athletic patient with articular cartilage lesions is often difficult and met with limited success. In this article we will discuss several types of knee articular cartilage injuries such as focal lesions, advanced full thickness lesions, and bone bruises. We will also discuss the risk factors for developing full thickness articular cartilage lesions and osteoarthritis, and describe the clinical evaluation and nonoperative treatment strategies for these types of lesions in athletes. *J Orthop Sports Phys Ther 2006;36(10):815-827.* doi:10.2519/jospt.2006.2303

Key Words: *chondral lesion, exercise, nonoperative treatment, nutrition, tibiofemoral joint*

Articular cartilage degeneration of the knee joint, osteoarthritis (OA), often occurs in the middle- to later-aged individual who has often become sedentary as a consequence of the disease. Focal articular cartilage injury, however, typically affects young athletically active individuals in their middle 20s into their late 30s, and represents a significant clinical challenge for the physician and rehabilitation specialist. Often this type of patient is an active sports participant who routinely exercises and may possess an active or strenuous work situation. In young, athletic patients the lesions are usually localized to 1 or possibly 2 compartments of the knee joint and represent a focal area that may vary in size from a relatively small (<2 cm^2) to a larger lesion of 8 to 10 cm^2. These lesions usually affect a weight-bearing portion of the joint or an area that receives significant loading when strenuous activities are performed.

The treatment plan for a young active patient with localized articular cartilage injury differs from that for an older patient with knee OA. Treating these 2 types of patients with the same rehabilitation plan is inappropriate because the pathology, activity levels, comorbidities, and patients' goals are tremendously different. Often our medical advice to the patient with OA is to "avoid performing weight-bearing exercise." Although the recommendation appears logical, it is not the most effective advice or best practice for the young athletic individual with a focal articular cartilage lesion. This type of patient is often highly motivated and desires an active lifestyle with exercise. We, as health care providers in the 21st century, must develop treatment strategies that effectively address and treat

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Patellofemoral Disorders: A Classification System and Clinical Guidelines for Nonoperative Rehabilitation

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Patellofemoral disorders are among the most common clinical conditions managed in the orthopaedic and sports medicine setting. Nonoperative intervention is typically the initial form of treatment for patellofemoral disorders; however, there is no consensus on the most effective method of treatment. Although numerous treatment options exist for patellofemoral patients, the indications and contraindications of each approach have not been well established. Additionally, there is no generally accepted classification scheme for patellofemoral disorders. In this paper, we will discuss a classification system to be used as the foundation for developing treatment strategies and interventions in the nonsurgical management of patients with patellofemoral pain and/or dysfunction. The classification system divides the patellofemoral disorders into eight groups, including: 1) patellar compression syndromes, 2) patellar instability, 3) biomechanical dysfunction, 4) direct patellar trauma, 5) soft tissue lesions, 6) overuse syndromes, 7) osteochondritis diseases, and 8) neurologic disorders. Treatment suggestions for each of the eight patellofemoral dysfunction categories will be briefly discussed.

Key Words: *patellofemoral dysfunction, rehabilitation, classification*

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Patients with patellofemoral pain symptoms remain one of the most vexatious clinical challenges in rehabilitative medicine despite the recent advancements in the understanding and treatment of other knee conditions. Dye (21) has referred to this clinical conundrum as the "Black Hole of Orthopaedics," stating that no single explanation or therapeutic approach has yet fully clarified this problem. This lack of understanding of patellofemoral pain and dysfunction is reflected in the vast number of different surgical procedures devised for the patellofemoral joint (22).

Patellofemoral disorders are probably the most common knee pathology encountered by the orthopaedic and sports medicine clinician. Several studies (31,63,98,110,121,123,124) have demonstrated that patellofemoral pain is one of the most common clinical conditions presenting to clinicians who treat musculoskeletal conditions. Unfortunately, there appears to be no consensus in the management of these conditions. There are certainly many reasons for this vacuousness of information, but perhaps one of the reasons is because of the many subtle variations of "patellofemoral pain." Additionally, central to the development of a rational therapy for these patients is an understanding of the genesis and pathophysiology of patellofemoral pain. Furthermore, it would appear that the ability to evaluate and differentiate these subtle variations and the differences in the pathophysiology of these patellofemoral disorders would enable the clinician to formulate effective treatment interventions based on the findings from the history, subjective examination, physical examination, and functional assessment.

The purpose of this article is to introduce a classification system that may be used as the foundation for treatment strategies and interventions for nonsurgical management of patients with patellofemoral pain. This proposed classification system has been formulated from previously published research and the clinical observations of the authors of this paper. In addition, this classification system was developed in an attempt to organize and offer suggestions on the application of the vast number of

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Principles of Patellofemoral Rehabilitation

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Summary: Patellofemoral disorders continue to present as some of the most common and challenging pathologic conditions of the orthopedic and sports medicine community. Numerous surgical and rehabilitative approaches have been suggested to treat patients with such conditions, but no single approach has been shown to be the most beneficial because of the numerous etiologic factors associated with patellofemoral pain. Rehabilitation programs should be implemented based on a thorough clinical evaluation and continuously modified based on the unique and specific presentation of each patient. Early emphasis is placed on eliminating pain and inflammation. In addition, reestablishing soft tissue and muscular balance is an essential component to patellofemoral rehabilitation programs. As the patient improves, the rehabilitation program is advanced in a progressive and sequential manner to ensure that adequate stress is applied to the injured tissues to facilitate healing while minimizing detrimental loads. This article outlines specific treatment principles commonly associated with nonoperative and postoperative patellofemoral management to restore function as quickly and safely as possible. **Key Words:** Knee—Non-operative rehabilitation—Exercise—Functional rehabilitation.

Disorders of the patellofemoral joint continue to present as some of the most perplexing pathologic conditions in orthopedics and sports medicine. Patellofemoral pathology has been referred to by Dye[1] as the "black hole of orthopedics" because of the lack of clarity regarding the etiologic factors that contribute to dysfunction or specific treatment protocols. This becomes evident when analyzing the myriad surgical and rehabilitative interventions that are used to alleviate symptoms and restore function in patients with patellofemoral disorders. It appears that no single surgical or rehabilitative approach can be effective in all cases.

Patellofemoral disorders often are considered the most common knee condition encountered by orthopedic and sports medicine clinicians.[2–8] In the general population, one of four persons likely will experience patellofemoral symptoms at some time.[9–13] Although patellofemoral disorders represent a common problem, there is no consensus regarding the optimal management of this condition, perhaps in part because of the various sources of pain that may contribute to the disorder. Unfortunately, terms such as "anterior knee pain" and "patellofemoral pain" have become accepted diagnoses with treatment often implemented without clear definitions of the underlying pathophysiology. The common use of such ambiguous and nonspecific terms adds to the confusion regarding optimal care for patients. The purpose of this article is to discuss current rehabilitation principles specific to the nonoperative and postoperative care of patients with patellofemoral disorders.

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REHABILITATION OVERVIEW

Rehabilitation programs designed for the patient with a patellofemoral disorder must match the specific disorder and dysfunction. Several authors have attempted to provide an explanation for the potential source of patellofemoral pain.

Dye et al[14] examined the conscious neurosensory mapping of the lead author's knee during arthroscopy without intraarticular anesthesia. The authors rated the level of conscious awareness from no sensation to severe pain. These findings were subdivided based on the ability to accurately localize the sensation. Palpation to the anterior synovial tissues, retinaculum, fat pad, and capsule

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Conscious Neurosensory Mapping of the Internal Structures of the Human Knee Without Intraarticular Anesthesia

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ABSTRACT

The conscious neurosensory characteristics of the internal components of the human knee were documented by instrumented arthroscopic palpation without intraarticular anesthesia. With only local anesthesia injected at the portal sites, the first author (SFD) had both knees inspected arthroscopically. Subjectively, he graded the sensation from no sensation (0) to severe pain (4), with a modifier of either accurate spatial localization (A) or poor spatial localization (B). The nature of the intraarticular sensation was variable, ranging from 0 on the patellar articular cartilage to 4A on the anterior synovium, fat pad, and joint capsule. The sensation arising from the cruciate ligaments ranged from 1 to 2B in the midportion, and from 3 to 4B at the insertion sites. The sensation from the meniscal cartilages ranged from 1B on the inner rim to 3B near the capsular margin. Innervation of most intraarticular components of the knee is probably crucial for tissue homeostasis. Failure of current intraarticular soft tissue reconstructions of the knee may be due, in part, to the lack of neurosensory restoration. Research studies of the knee designed to delineate factors that restore neurosensory characteristics of the musculoskeletal system may lead to techniques that result in true restoration of joint homeostasis and function.

The human knee is one of the most complex systems in the body. The asymmetrical components of the knee act in concert as a type of biologic transmission that accepts, transfers, and dissipates loads among the femur, tibia, patella, and fibula.[9] The ligaments act as adaptive linkages, with the menisci representing mobile bearings. Current data indirectly indicate that various intraarticular components of the knee are sensate, that is, they generate neurosensory signals that reach the spinal, cerebellar, and higher central nervous system levels. These signals ultimately result in conscious perception. The main research studies supporting this belief have been based on histologic evidence of neural structures within intraarticular components,[4,7,14–17,19,20,23,28,29,34,35] the documentation of sensory evoked potentials,[26] or on proprioceptive characteristics of the human knee.[2,3,6,24,27,30,31] Proprioceptive studies have been primarily designed to elicit conscious detection of small movements of the knee. Such data summarize neurosensory output from the entire joint and limb, including the extraarticular structures; thus, they do not isolate possible intraarticular sensory signals. Documentation of sensory evoked potentials with electrical stimulation of intraarticular structures of anesthetized patients at surgery does not address the question of whether and to what extent a person would consciously experience palpation of those structures.

We (SFD and GLV) concluded that a simple method to directly document possible conscious neurosensory perception of the intraarticular components of the human knee would be to arthroscopically palpate the components without intraarticular anesthesia and record the subjective experience. We are aware of no prior studies that have attempted such neurosensory documentation. Our purpose, therefore, was to document conscious neurosensory mapping of the intraarticular components of the human knee by means of arthroscopic instrumented palpation without intraarticular anesthesia.

MATERIALS AND METHODS

Both knees of the first author (SFD) were inspected arthroscopically by the second author (GLV). The right knee

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Rehabilitation Programs for the PCL-Injured and Reconstructed Knee

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Treatment of posterior cruciate ligament (PCL) injuries has changed considerably in recent years. This article discusses current rehabilitation for PCL disruptions in athletes. The treatment of PCL injuries varies somewhat based on the chronicity (acute vs. chronic) of injury and associated pathologies. The authors provide their treatment algorithm for the acute and chronic PCL-injured-knee patient. Nonoperative rehabilitation is discussed with a focus on immediate motion, quadriceps muscle strengthening, and functional rehabilitation. A discussion of the biomechanics of exercise is provided, with a focus on tibiofemoral shear forces and PCL strains. Surgical treatment is also discussed, with the current surgical approach being either the two-tunnel or the one-tunnel patellar tendon autograft procedure. The rehabilitation program after surgery is based on the healing constraints, surgical technique, biomechanics of the PCL during functional activities, and exercise. With the new changes in surgical technique and in the rehabilitation process, the authors believe that the outcome after PCL reconstruction will be enhanced.

Key Words: posterior cruciate ligament, rehabilitation, two-tunnel PCL reconstruction

Injuries to the posterior cruciate ligament (PCL) were thought to be rare clinical entities; however, this type of ligamentous injury appears to be more common than once believed. Several authors have reported an incidence of PCL injuries between 9% and 38% in their studies of ligamentous knee injuries (2, 4–6, 14), whereas some have stated an incidence as low as 1% (17, 30). Johnson and

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