Anterior knee pain is the most common complaint in the runner or bicyclist, and patellofemoral stress syndrome the most frequent diagnosis. This paper reviews patellofemoral anatomy, contact areas, articular cartilage abnormalities, and biomechanics during exercise and athletic activities. Causative factors in these overuse syndromes are intrinsic (anatomic malalignment, patella subluxation, quadriceps imbalance, medial plica) and extrinsic (mechanical overload, changes in training patterns or equipment). Differential diagnosis, rehabilitation plans, and surgical procedures are outlined. History and training patterns in the endurance athlete are quite important. Physical findings and lower extremity alignment in normal persons and patients with "miserable malalignment syndrome" are presented. A rehabilitation program of quadriceps strengthening by isometric straight leg raising exercises and hamstring stretching is the mainstay of treatment. Arthroscopy is not curative in patellofemoral disorders. An understanding of normal patellofemoral anatomy and biomechanics allows for easier diagnosis and the formulation of logical and successful treatment plans.

PATELLOFEMORAL DISORDERS IN RUNNERS AND BICYCLISTS

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Anterior knee pain is the most common complaint in the endurance athlete. Derangements of the patellofemoral (PF) joint can be more easily diagnosed and treated if the principles of anatomy and biomechanics are understood and applied. This report correlates PF anatomy, biomechanics, and pathologic articular cartilage changes with the patient's symptoms and with clinical and radiographic signs. The PF biomechanics and differential diagnosis for such complaints in runners and bicyclists is reviewed. Excellent clinical presentations on PF problems in the literature are cited.[1-12]

ANATOMY

PF joint anatomy has been well described in texts[1-3,13] and journals.[14-19] Although descriptions of the patellar facets vary, the two main facets are medial and lateral (Figure 1). The lateral facet is flatter and larger by a 3:2 ratio than the medial. The odd facet is a third unpaired area separated from the medial facet by a prominent ridge. In 30% of patellae there is a well-defined odd facet.[14] A superior and inferior nonarticulating facet can also be present. The posterior portion of PF articulation is the "pulley-shaped" trochlea of the femur. This consists of two convex facets (medial and lateral) and a central groove. The shape of the patellar facets, trochlear groove, and sulcus angle influence patellar stability and contact areas. In addition to bony con-

gruency, important factors in patellar tracking include balanced vectors from lower extremity alignment, the quadriceps mechanism, PF and patellotibial ligaments, lateral retinaculum and the patellar tendon.

The multiple functions of the patella have been well described.[1,3,8,20,21] The patella increases the quadriceps mechanism's moment arm and hence improves efficiency and mechanical advantage for knee extensions. This is believed to be its most important function. It acts to centralize the divergent heads of the quadriceps mechanism by neutralizing the four different vectors of the vasti. Aesthetically, the patella improves the appearance of the anterior knee, which can be better appreciated with increasing knee flexion. As the largest sesamoid in the body, the patella acts as a bony shield to protect the trochlear groove. It protects the patellar and quadriceps tendons from friction and wear, allowing these tendons to tolerate high repetitive loads. The articular cartilage of the PF joint distributes compressive and shear forces to the subchondral bone. The cartilage provides a low coefficient of friction and aids in joint lubrication. Normally this PF articulation endures a lifetime of extensive wear and forces.

CONTACT AREAS

With increasing knee flexion, the area of contact of the PF reaction and force between the patella and femur increases. As the knee flexes, the femoral contact area moves from proximal to distal while the patella moves from distal to proximal.[18,22] Using impression techniques, Aglietti et al.[22] loaded ca-
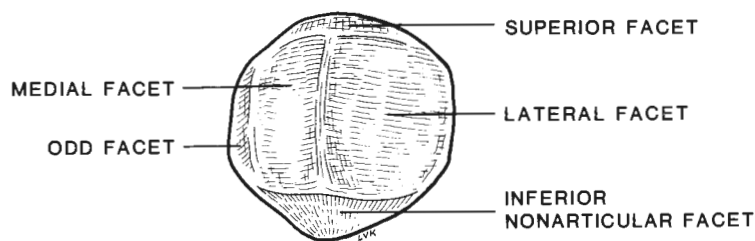
Figure 1. Patellar articular surface consists of odd, medial, and lateral facets. Superior and inferior nonarticular facets are shown.

daver knees to determine PF contact areas (Figure 2). Initial PF contact occurred at 30° flexion between the lateral patellar facet and lateral femur. At 60° flexion the patellar contact area moved inferomedially and, at 90°, contacted the femoral groove just above the notch. The broadest PF contact areas and potential for least load per unit area occur up to 90° flexion in cadaver studies (when the joints are loaded from above).[18,22] From 90° to 135° the contact area decreases and concentrates on the superior ridge of the patellar cartilage. Then, at 135°, the odd and lateral facets contact the trochlea.[18] Huberti[23] and Ficat and Hungerford[1] have shown that the range of PF contact is from 20° to 120°. Normally the PF joint contact pressures remain uniform, but cartilage breakdown occurs when the physiologic limits of load per unit area are exceeded.

ARTICULAR CARTILAGE AND CHONDROMALACIA

Excellent studies[24,25] have reviewed the properties of articular cartilage and its response to injury. The anatomic organization into four zones, tidemark, changes in water content, and proteoglycans are factors that render cartilage resilient and able to resist compressive and shear forces.[24,25] Mechanical overload, as occurs in repetitive running or cutting

activities or with anatomic malalignment, can lead to destruction if the contact area exceeds the physiologic limits of load per unit area.[18,26] Histologically, cartilage has limited repair potential.[25] Its breakdown has been studied by gross and histologic examination. Outerbridge[27] described the pathology of four grades of cartilaginous change, termed "chondromalacia," or "soft cartilage." Grade I is softening. Grade II changes include superficial fibrillation or fissuring. Grade III changes are deeper fibrillation and coarse fissuring down to subchondral bone, described as being like "crabmeat" in appearance. Grade IV changes are erosion and exposed bone. The two sites commonly involved with more severe chondromalacic changes are the ridge separating the odd and medial facets and the inferior ridge between the medial and lateral facets.[17] Goodfellow also noted that chondromalacic changes of the medial facet were more common in younger patients. The lateral facet is more commonly involved in osteoarthritis. Bentley[15] estimated that chondromalacic changes were present in 50% of patients with PF disorders. The use of the term chondromalacia should be limited to palpable or observed changes seen at the time of arthroscopy or arthrotomy.
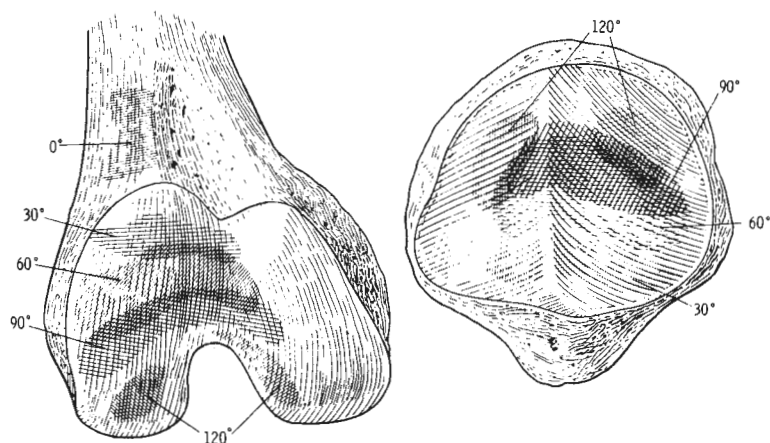

Figure 2. Patellofemoral contact areas are shaded at 0°, 30°, 60°, 90°, and 120° flexion in this right knee diagram. Femur (lateral to left and medial to right) and patella (lateral to right and medial to left) are shown. (From Aglietti P, Insall JN, Walker PS. A new patellar prosthesis. Clin Orthop 107:175, 1975. Reprinted with permission.)

BIOMECHANICS

Texts[1,2,10,13,20,28,29,30,31] and articles[32-37] describe the biomechanics of the PF joint during specific exercises and activities. The four major forces acting upon the patella include the quadriceps, patellar tendon tension, and the contact area between the medial and lateral facets.[31] The contact areas vary with foot position, activity type, and intensity. The patellofemoral joint reaction force (PFJRF) is determined by the degree of knee flexion and the magnitude of quadriceps and patellar tendon force. PF and tibiofemoral forces on the knee reach a maximum at midstance in the gait cycle.[9,30,38] Reilly and Mastens[9] measured PFJRF during normal walking as 50% of body weight requiring low-angle arcs, less than quadriceps muscle force. Mann[38] described muscle activity during walking, jogging, and running. During walking and jogging the quadriceps act at heel strike and early stance to resist further knee flexion. During running the quadriceps also acts to extend the knee during midswing. A double float phase also occurs during running, and the duration of the stance phase decreases to one-third as compared to walking. In running, the maximum PFJR and tibiofemoral forces occur at midsupport, with the axial load at 200% of body weight and flexion force at 15% of body weight times height.[30] Andriacchi[30] found a 5.8-fold increase in flexion moment torques from level walking to running. Peak flexion is 60° in walking and 110° in running, and occurs during midswing.[32] Biking requires 100% knee flexion. During bicycling the gastroscoleus and quadriceps muscles are active because of the plantar flexing the foot and the extension of the knee during the pedal cycle.[39]

The PFJR force, quadriceps tension, and moment arm have been determined in different degrees of flexion and during many activities.[28-32,35-37,40-42] During dynamic action, factors influencing joint reaction forces are acceleration and mass moment of inertia.[28,29,31] For example, during an isometric contraction, Perry et al.[40] found quadriceps tension to be 1.8 × body weight (BW) at 5°, 4 × BW at 30° and 6 × BW at 60°. Schmidt[35] found quadriceps tension to be 1.7 × BW at 5°, 2.7 × BW at 30°, and 3.2 × BW at 60°. Morrison[36] estimated quadriceps tension to be 2.4 × BW when descending stairs at the required 60° knee flexion and 2.8 × BW when ascending stairs at 45° flexion. Exercises such as 90° deep knee bends increase to 7.6 × BW.[41] Fulkerson[10] believed mechanical overload to be the primary cause of PF symptoms. If the amount of knee flexion, PFJR forces, and specifics of the activity are known, then rational treatment and rehabilitation programs can be designed.
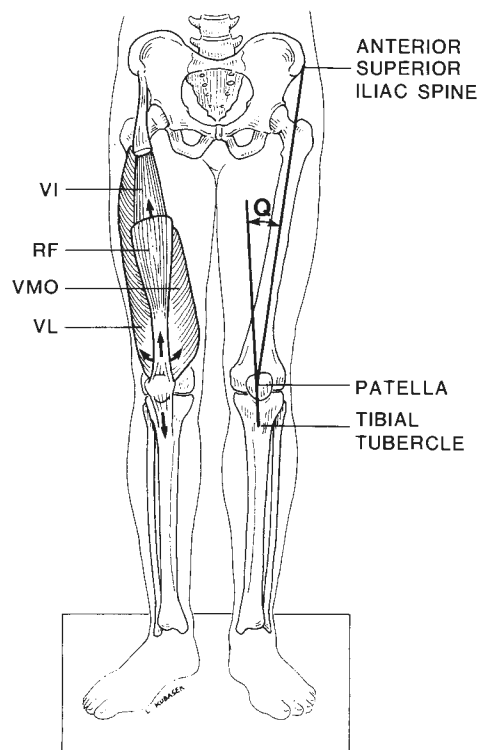

Figure 3. Normal dynamic quadriceps muscle forces and Q angle measurement are shown. Four balanced vastus forces, normal lower-extremity alignment and Q angle (≤15°) result in central patellar tracking.

HISTORY

A detailed history of the runner or bicyclist is mandatory but time consuming. Pain patterns should be noted, i.e., timing, character, and methods of relief. In the runner, questions should also focus on age or changes in running or work shoes, the use of orthotics, and changes in terrain or mileage. In bicycling, the height of the seat, use of toe clips, level of resistance, and the intensity and duration of training are important factors. These changes in extrinsic factors may be overlooked by the endurance athlete. However, the patient's history and details of minor training changes may be the most helpful factors in diagnosis and treatment.[43]

PHYSICAL EXAMINATION

Central tracking of the PF joint is dependent on a balanced quadriceps mechanism and lower-extremity alignment. Patients are examined as they stand, sit, walk, and run to monitor patellar tracking and quadriceps action. Alignment, rotation, and patellar position are noted while the patient is standing (Figure 3). The rectus femoris (RF) and vastus intermedius (VI) direct the forces vertically. The vastus medialis obliquus (VMO) and vastus lateralis (VL)
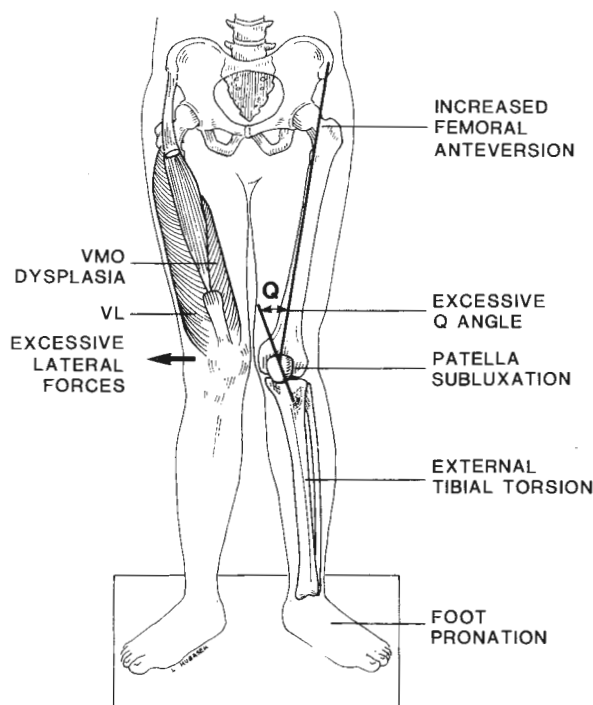
Figure 4. Miserable malalignment syndrome results when excessive lateral forces (Q angle > 15°, femoral anteversion, hypoplastic VMO, external tibial torsion) cause abnormal patellar tracking and subluxation.

are inserted by a retinaculum into the medial and lateral sides of the patella. Lieb and Perry [42] determined that the VMO does not contribute to extensor force, but stabilizes the patella medially. A second group of separately innervated long fibers of the vastus medialis (an extensor only) was designated in this study. VMO atrophy reflects generalized quadriceps weakness but is more easily seen because of the VMO's obliquity and thinner fascia.

The Q or quadriceps angle[3,44–46,51] is measured with the patient supine from the anterior superior iliac spine to the center of the patella and from the center of the patella to the tibial tubercle. Normally this angle is less than 15° in females and less than 7° in males. Insall[45] measured normal patients with Q angles up to 20° and found that this angle increased in patients with chondromalacia. With the knee flexed to 90°, this angle is normally 0°.

"Miserable malalignment syndrome"[11,42,44,46] has been used to describe lower-extremity alignment with excessive lateral vectors, resulting in patellar subluxation and symptoms (Figure 4). Patients with this syndrome have increased femoral anteversion, an excessive Q angle, squinting or infacing patellae, hypoplastic VMO, and external tibial torsion. Other factors which are associated with this syndrome include genu valgum, patella alta, tibia vara, foot pronation, and generalized increased laxity.[30] Active

and passive range-of-motion measurements of the thoracic and lumbar spine, hip, ankle, and subtalar joint are made. The flexibility of the lumbodorsal fascia, iliotibial band, hamstrings, Achilles tendon, and plantar fascia is noted. Several minor abnormalities may contribute to PF symptoms in the endurance athlete.

A systematic knee exam is performed.[46,47] Range of motion, hamstring tightness, quadriceps girth, meniscal signs, and knee ligament stability are recorded. The patellar facets are palpated for localized tenderness. Patellar stability is tested at 30° flexion with the quadriceps relaxed. The amount of subluxation and apprehension signs are noted. The severity of the knee flexion angle when crepitus and pain occur during patellar compression or when rising from a squatting position are recorded. The area of the medial plica is palpated for the synovial band, which may be large and painful. Quadriceps girth and manual muscle testing of the knee extensors and hip flexors is performed.

RADIOGRAPHS

Numerous in-depth reviews[1,3,48–51] of techniques, normal measurements and the importance of special patellar views have been written. An especially useful and reproducible view is that of Hughston.[2,51] Both patella can be obtained on one film for comparison. The patient is prone with knees at 55° flexion. Patella alta and infera (baja) is determined radiographically on a lateral view by Insall's[3,45] criteria. The ratio of patella to patellar tendon length of less than 0.8 indicates alta; a ratio greater than 1.2 indicates infera. Patellar views may demonstrate an excessive lateral tilt, subluxation, or osteochondral fracture. Unfortunately, in injuries resulting from overuse, the plain radiographs are usually normal and thus provide little aid in the diagnosis or management of the patient.

DIFFERENTIAL DIAGNOSIS

Numerous articles[4–6,8–18,27–30,45,46] and texts[1–3] outline the causes of knee pain in the endurance athlete. The three main categories include inflammatory, mechanical, and miscellaneous causes (Table 1). Inflammation of the bursa (pre- or retropatellar, pes anserinus), tendons (pes anserinus, semimembranosus, inferior patellar), or synovium, is common. The most common cause of anterior knee pain is the PF stress syndrome, incorrectly termed chondromalacia, which is a pathologic, not a clinical, diagnosis. The other mechanical causes of PF symptoms are patellar hypermobility, subluxation, dislocation, pathologic plica syndrome, osteochondral fracture, and arthrosis. The rarer miscellaneous

Table 1. Differential diagnosis of anterior knee pain.

Inflammatory	Mechanical	Miscellaneous
Bursitis	Hypermobility	Reflex sympathetic dystrophy
Prepatellar	Subluxation	Osteochondritis dissecans
Retropatellar	Dislocation	Fat-pad syndrome
Pes anserinus	Patellofemoral stress syndrome	Systemic arthritides
	Pathologic plica syndrome	Muscle strain
Tendonitis	Osteochondral fracture	Stress fracture
Pes anserinus	Arthrosis	Meniscal tear
Semimembranosus		Iliotibial band syndrome
Patellar		
Synovitis		

causes include reflex sympathetic dystrophy, osteochondritis dissecans, fat-pad syndrome, systemic arthritides, muscle strain, stress fracture, meniscal tear, and iliotibial band syndrome. Rehabilitation and surgical treatment plans can be tailored by modifying the inflammatory, mechanical, or miscellaneous causative factors.

TREATMENT

General. Texts[1-3,13] and articles on rehabilitation[39,52-56] and surgery[31,33,45,46,49,51] for PF disorders offer excellent reviews. Relative rest through modified training patterns (e.g., of intensity, duration, types of terrain) may ease symptoms of anterior knee pain. For example, the PF joint reaction force is increased from grass to asphalt to concrete surfaces and from level to uphill to downhill grades. Running on level grass may provide the rest needed to relieve the symptoms from medial plica or PF stress syndrome. Anti-inflammatory medications may be added for several weeks. It may become necessary to alter the type of shoes used, adjust bicycle seat height or cam type, add or change orthotics, or use patellar straps or braces.

Rehabilitation. The goals of rehabilitation are improvement in flexibility and quadriceps strength. Warming and stretching tight or injured muscle groups before and after training sessions can be helpful. Nonballistic, self-administered hamstring stretching should be carried out prior to exercise (Figure 5). Isometric straight leg raising (SLR) exercises should be performed in a supine or partially sitting position, with the knee slightly flexed, using distal ankle weights (Figure 6); the weights are increased to 10 lb and the repetitions to several hundred, depending on the patient. The contralateral knee is flexed to prevent low-back symptoms. Due to the minimal PFJR forces and because there are no areas of PF articular contact, these exercises are well tolerated even by patients with a painful knee. The use of isokinetic or variable-resistance machines from flexion to extension may worsen

symptoms, especially in a patient with an acutely painful knee.

Research[1,18,41] has shown that loading the PF joint from above, as in squats, and from the foot, as in leg presses, rather than loading anterior to the distal tibia, produces less PF joint reaction force. Reilly and Martens[41] demonstrated a significant difference in PF joint reaction force when the distal tibia was loaded anteriorly or inferiorly. When a 9-kg boot was resisted anteriorly with force perpendicular to the long axis, peak load occurred at 90° at 1.4 × BW. With distal load the peak occurred at 36° at 1.4 × BW. Compared to flexion from 90° to 20°, extension from 20° to 0° requires a 60% increase in
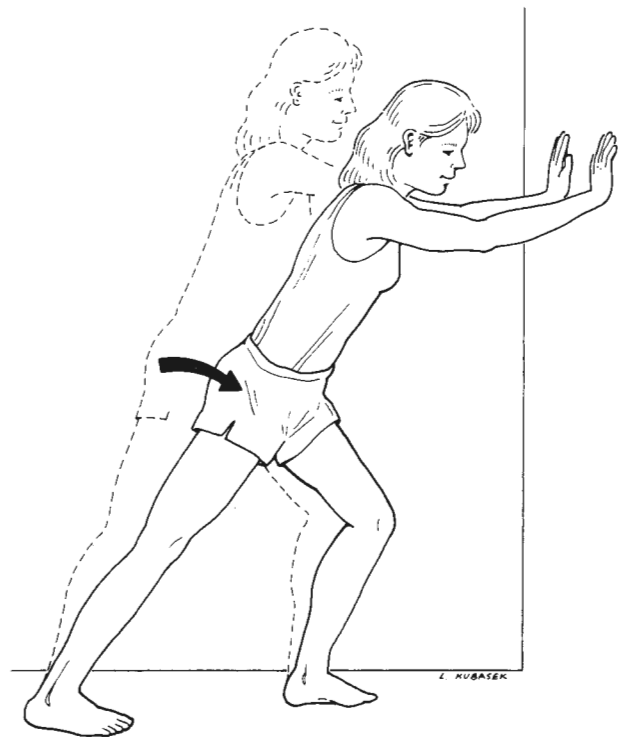

Figure 5. Method of hamstring stretching. With knee extended and heel off floor the patient leans and pushes against the wall and pushes heel toward floor.
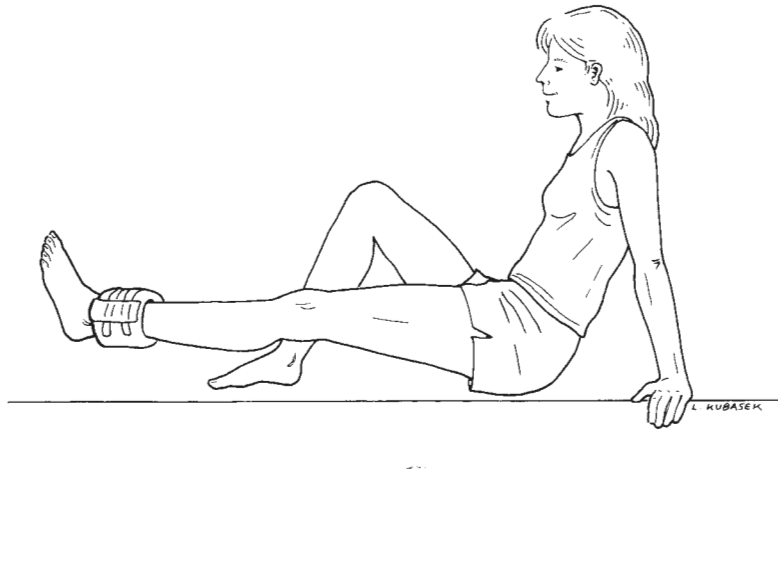
Figure 6. Technique for straight leg raising exercises. Supine or in a semisitting position with opposite knee flexed, the patient lifts leg with knee in slight flexion. Advancement to several hundred repetitions and 10 lb is recommended.

quadriceps force.[42,56] Higher flexion angles, i.e., squats at 90°, should be avoided because the PFJR forces are maximal, owing to increased flexor moment arm.[41] Stationary bicycling with moderate resistance and a high seat height and swimming are usually well tolerated and recommended.

SURGERY

The multiple surgical procedures for debridement and realignment of the PF joint have been well described in texts[1-3,13] and articles[31,46,49,51] and are beyond the scope of this paper. These procedures include debridement, lateral release by arthrotomy or arthroscopy, chondrectomy, facetectomy, drilling, and proximal or distal patellar realignment. Arthroscopic procedures should be considered only if all conservative measures fail.

Although the PF joint is the joint most accessible to the arthroscope, the temptation to use this method should be resisted until rehabilitation and modification activities have been attempted. It has been said that if neurosurgeons operated for headaches as often as orthopedists do for patellar problems, there would be a lot more burr holes in the world.

A diagnostic arthroscopy of the PF joint should quantitate the depth and surface area of articular cartilage chondromalacia and observe patellar tracking. In operative arthroscopy, debridement and abrasion chondroplasty of the friable cartilage will decrease contact forces, articular stress, and the coefficient of friction and increase the weight-bearing surface. Arthroscopic debridement in the osteoarthritic knee does not correct anatomic malalignment or change the synovial milieu of destructive en-zymes. Transarthroscopic lateral release may improve symptoms, but should be done with caution in carefully selected patients. Medial subluxation can occur following lateral release in patients with ligamentous laxity. Arthroscopic debridement of patellar and trochlear groove defects results in a smoother gliding surface, but is not curative. Examples of arthroscopic treatment for varying grades of chondromalacia of the PF joint and medial plica syndrome show slow improvement over the course of up to 12 months. A similar rehabilitation program should be continued following surgery.

DISCUSSION

Since articular cartilage is aneural, avascular, and alymphatic, it is surprising that this PF joint is so great a clinical problem. The reasons for pain in patients with chondromalacia patella have been theorized as increased osseous pressure; microfracture; excessive load transmitted down to subchondral bone, which has nerve endings; and synovial effusion irritating the richly innervated synovium. Further investigation is warranted to correlate articular cartilage abnormalities and biomechanics with symptoms, the clinical exam, and treatment.

The most common diagnosis in the runner or bicyclist is PF stress syndrome, sometimes associated with pathologic plica, subluxation, malalignment, and inflammation. Pain is a protective mechanism and should be investigated. A rehabilitation program is the mainstay of treatment for anterior knee pain. Intrinsic anatomic factors of malalignment and patellar subluxation must be documented during the

physical exam. An alteration in extrinsic factors may improve PF symptoms. These factors include bicycle seat height, running terrain, intensity and duration of running or bicycling, and the use of painless training modalities, such as swimming. Open operative procedures may be indicated if there are anatomic factors causing altered PF mechanics. Although technically easy, arthroscopy is helpful in diagnosing the existence and extent of articular cartilage damage and in debriding synovium and osteochondral defects and diluting the synovial fluid. It temporarily improves PF symptoms but is not curative. Even after arthroscopy, the rehabilitation program is the mainstay of treatment.

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