CURRENT CONCEPTS REVIEW

PATELLOFEMORAL ARTHRITIS

BY RONALD P. GRELSAMER, MD, AND DREW A. STEIN, MD

- The surgeon must determine whether patellofemoral arthritis is the primary source of a patient's knee pain and whether the arthritis is truly unicompartmental.
- An anteromedial osteotomy of the tibial tuberosity is most effective when the arthritis is localized to the distal-lateral portion of the patellofemoral compartment. It is least effective when there is global arthritis of the patellofemoral articulation.
- Total knee arthroplasty is an effective treatment for patellofemoral arthritis.
- Patellofemoral replacement can be considered for selected patients.
- A major reason for poor results after patellofemoral replacement and patellectomy procedures is the development of femorotibial arthritis.

Unicompartmental arthritis is traditionally thought of as a condition affecting the femorotibial compartments, but it can also be isolated to the patellofemoral articulation. In fact, isolated patellofemoral arthritis may not be so rare[1-3]. In a radiographic study of patients over the age of forty years who had painful knees, Davies et al.[2] noted that the prevalence of isolated patellofemoral arthritis was 9% (nineteen of 206 knees). McAlindon et al.[4] performed a radiographic study of 273 symptomatic knees in patients over the age of fifty-five years and found a prevalence of isolated patellofemoral arthritis of 8% in women. The condition also exists, albeit at a lower frequency, in young and middle-aged people.

When encountering a patient with isolated patellofemoral arthritis for whom a nonoperative approach and perhaps an arthroscopic débridement have failed, the orthopaedic surgeon can choose from a number of operations, including total knee arthroplasty and tibial tuberosity transfers as well as lateral retinacular releases, patellofemoral replacements, autologous chondrocyte implantation, facetectomy, removal of the patellar subchondral bone, and denervation.

Although a total knee replacement can address any and all arthritic conditions about the knee, the surgeon may consider this to be an overly aggressive approach in the setting of unicompartmental arthritis. This would be particularly true in a young, active patient, for whom the surgeon would want the most bone-sparing procedure, and in an older, more frail patient, for whom the surgeon would want to minimize surgical dissection, operating time, and blood loss. The surgeon therefore can choose between a relatively extreme procedure with predictable results (total knee replacement) and operations demanding less surgical dissection and resection but offering less certainty. In this review, we will summarize the current thinking regarding these various options.

Etiology

As is true of all articular cartilage, the articular cartilage of the patella consists of a solid phase, made up mostly of collagen and glycosaminoglycans, and a fluid phase. The solid phase is slightly permeable, and, when a load is applied to the articular surface, the fluid slowly redistributes itself within the solid matrix[5,6]. The pressure within the fluid is largely responsible for the cushioning effect of the articular cartilage as well as the low friction coefficient exhibited by the cartilaginous surfaces. Disruption of the articular surface by cracks, fissures, crevices, and the like leads to a loss of pressure within the fluid phase. High stresses are then borne by the collagen fibers, which become more prone to breakdown[7]. The ability of collagen to withstand high stresses has a variable genetic component[8], which accounts for the wide range of clinical responses to a given joint load among different patients. For the purposes of this review, the term *arthritis* refers to full-thickness loss of articular cartilage and concomitant inflammation.

Wear and damage of articular cartilage can have a biological or mechanical cause. Biological causes include inflammatory diseases and infection, although neither leads to isolated patellofemoral arthritis. Mechanical causes include all conditions associated with loads that overwhelm the capacity of cartilage to withstand them. These conditions include any combination of obesity, repetitive deep knee flexion, malalignment[9,10], dysplasia, and blunt trauma. The prevalence of osteoarthritis of the knee is higher in obese in-

dividuals, presumably as a result of increased loads placed on all parts of the joint[11].

One part or another of the patellar cartilage remains loaded throughout the entire flexion-extension cycle, with the exception of the earliest degrees of flexion[12]. The distal portion of the patella is loaded as the knee flexes, and the contact area on the patella migrates proximally with progressive flexion. At 90°, the contact area is located proximally, after which the contact area moves back toward the central aspect of the patella. Thus, the central portion of the patella is the part that is most frequently loaded. It also happens to be the part of the patella that exhibits the thickest cartilage (5 mm)—in fact, the thickest cartilage in the human body[12].

Most activities involving knee flexion take place in a closed-kinetic-chain mode whereby the foot is on the ground. These activities include bending down, rising from a chair, and ascending stairs. Activities involving repeated bending against resistance (with body weight being the most common resistance) also lead to stresses across the patellofemoral joint. In a closed-chain mode, the forces across the patellofemoral joint increase as the knee flexes from 0° to 90°, as do the contact pressures (force per unit area)[13].

An improper fit between two mating surfaces leads to an abnormal stress distribution. Rotational malalignment in the axial plane[9] (posterior tilt of the lateral border of the patella) results in abnormally high lateral stresses[14-17] that can lead to arthritis[18]. A dysplastic trochlea, whereby the trochlea is flat or even convex, can also lead to unusually high loads and the development of arthritis in younger patients.

Diagnosis of Isolated Patellofemoral Arthritis

Pain is the primary symptom that should be addressed, and the surgeon must first correctly identify the source of this pain. This can be particularly challenging with the patellofemoral joint, as a large number of conditions can refer pain to the anterior aspect of the knee. These conditions include overuse, abnormal patellar tilt, plicae, neuromas, tendinitis, synovitis, and focal lesions within the patella. In addition, pain can be referred from elsewhere in the knee or from distant sites such as the hip or spine. It is tempting to attribute pain to physical changes that are clearly visible on a radiograph, on a magnetic resonance imaging scan, or to the naked eye; however, the major source of a patient's pain may in fact be abnormal intraosseous pressures, abnormal levels of biochemical mediators such as proinflammatory cytokines or substance P[19], or other factors that are not readily apparent. The enhanced ability of modern imaging modalities to visualize the articular surface of the patellofemoral joint has not improved the surgeon's ability to treat patellofemoral pain[20]. This was well stated by Insall when he noted "Curiously, neither the widespread use of arthroscopy nor the advent of new diagnostic tests such as CT scanning and magnetic resonance imaging have cast much light" on the enigma of patellofemoral pain[21,22].

A patient with isolated patellofemoral arthritis typically describes anterior knee pain when rising from a seated position and/or ascending stairs[23]. The pain is diminished when the subject walks on level ground. Pain at rest should arouse suspicion of nerve-related pain, such as a neuroma, reflex sympathetic dystrophy/complex regional pain syndrome, or a radiculopathy. More rarely, pain at rest can be associated with a patellar tumor, an infection, or a stress fracture.

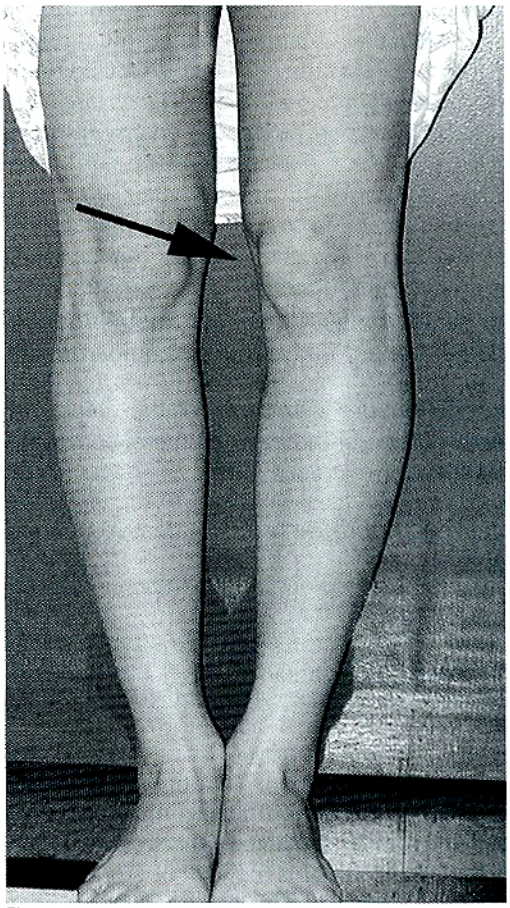

Fig. 1

The squinting patella. The patella points inwards. This finding is associated with femoral anteversion.

On the physical examination, the surgeon should observe the patient in the standing and walking position and look for a squinting (inward-pointing) patella (Fig. 1), foot pronation, and other signs of distant, pain-producing pathological conditions. With the patient seated or supine, the hips should be evaluated for signs of tightness, synovitis, and joint inflammation, since pathological conditions of the hip can present as anterior knee pain. When assessing the knee, the examiner should begin with light palpation of the soft tissues to detect a neuroma or tendinitis. This is particularly important because no current imaging study predictably reveals these conditions. If they are not diagnosed at the time of the physical examination, they may be missed completely. The presence or absence of patellar tilt needs to be determined on the physical examination[10], since many imaging reports fail to make note of it.

A key sign of *symptomatic* patellofemoral arthritis on the physical examination is tenderness of the lateral (or occa-

sionally medial) facet of the patella[10]. The examiner assesses this by gently curling the fingers under the lateral (or medial) border of the patella. In the setting of clinically meaningful patellofemoral arthritis, this causes pain. (In applying pressure to the facet, the examiner is simultaneously applying pressure to all of the soft tissues between the skin and bone, including the retinaculum and the synovium. The specific source of the pain can therefore be debated.)

The critical imaging study is the Merchant radiograph, for which the patient is placed supine on the imaging table with the knees angled over the end of the table and supported by a variable angle device[24] (Fig. 2). It is imperative that there not be overlap between the patella and the underlying trochlea, so that apparent approximation of the two structures represents true joint-space narrowing rather than a radiographic artifact. Although the original article by Merchant et al. described a knee flexion angle of 45°[24], lesser angles, such as 30°, are more desirable as they allow imaging of a more proximal portion of the patellofemoral joint. Since trochlear dysplasias are most commonly proximal, it is imperative that this portion of the compartment be visualized. Although one may choose magnetic resonance imaging or computerized tomography over a well-made Merchant radiograph, these are not cost-effective methods for arriving at the same conclusions.

Having judged that the patellofemoral compartment is an important source of pain, one must determine whether the arthritis is truly isolated to this compartment. The absence of joint line tenderness is insufficient evidence that femorotibial arthritis is absent, and one must not fail to order a complete set of radiographs. These include not only standing anteroposterior, true lateral[25], and Merchant radiographs, but also the standing tunnel view, also known as the *Rosenberg view*[26,27] or the *schuss view* because of the crude resemblance to a schussing skier[23] (Fig. 3). When made adequately, the standing tunnel view is indistinguishable from a supine tunnel view, inasmuch as there is no overlap between the femur and tibia and the notch is clearly visible. It is a critical projection because often it alone reveals arthritis that is localized to the central and posterior aspects of the femorotibial compartments (Figs. 4-A and 4-B).

Magnetic resonance imaging and arthroscopy can also be useful for evaluating the femorotibial compartments, as can a nuclear bone scan, the only imaging modality that provides a measure of a compartment's metabolic activity.

A controversial issue is the extent to which nonarthritic chondral changes (e.g., partial-thickness defects) can be present in other compartments before the patellofemoral arthritis can no longer be considered isolated. Corpe and Engh[28] investigated a similar issue in their evaluation of isolated unicompartmental arthritis of the femorotibial articulation. In a study of patients who had undergone femorotibial unicompartmental knee replacement, they noted that scattered non-full-thickness chondral changes in the untreated compartments did not affect the results. It is not known whether these findings can be extrapolated to the patellofemoral joint.

Patellofemoral arthritis can be a subtle reflection of otherwise subclinical inflammatory arthritis. Serum analysis for inflammatory conditions such as rheumatoid arthritis is warranted, and in the United States an infectious workup for Lyme disease should also be considered[29].

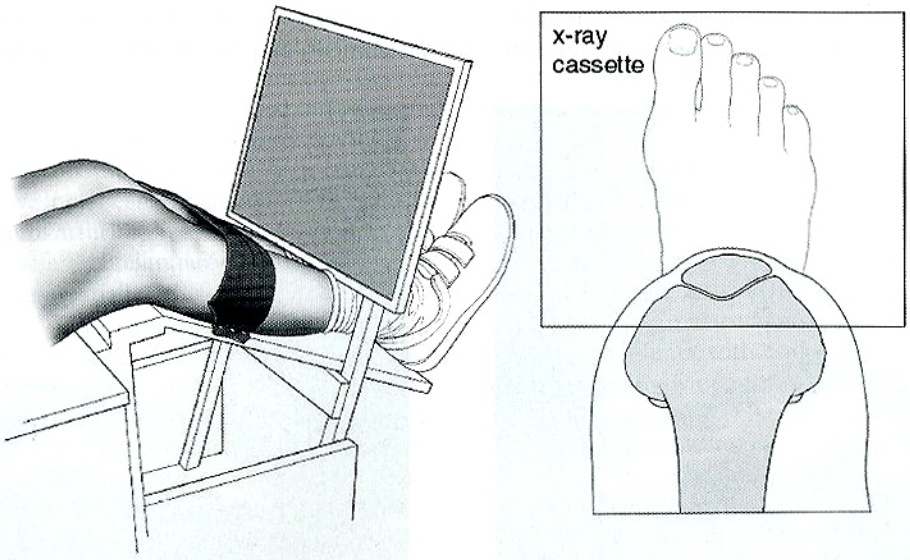

Fig. 2

The Merchant radiograph is made by placing the leg on an angled (Merchant) board that projects from the end of the imaging table. Use of the Merchant board allows the knee to be imaged at a flexion angle of 30°, so that the proximal portion of the trochlea, where dysplasia manifests itself, can be visualized. (Reprinted, with permission, from: Grelsamer RP, Weinstein CH. Patellar instability. In: Callaghan JJ, Rosenberg AG, Rubash HE, Simonian PT, Wickiewicz TL, editors. The adult knee. Philadelphia: Lippincott Williams and Wilkins; 2003. p 929-40.

Fig. 3

The Rosenberg ("schuss") radiograph. This standing view reveals arthritis localized to the posterior aspect of the femorotibial compartments.

Evaluating the Outcome of Patellofemoral Procedures

Few outcome instruments were designed specifically for the assessment of the patellofemoral joint[30], and none has been uniformly accepted by surgeons experienced in the treatment of patellofemoral disease. The development of such an instrument is difficult because of the potentially different expectations for the function of this joint among patients in different age groups. Therefore, an outcome instrument that targets older patients with arthritis, such as the popular Western Ontario and McMaster Universities Osteoarthritis (WOMAC) instrument, may be overly favorable to patients with patello-

Fig. 4-A

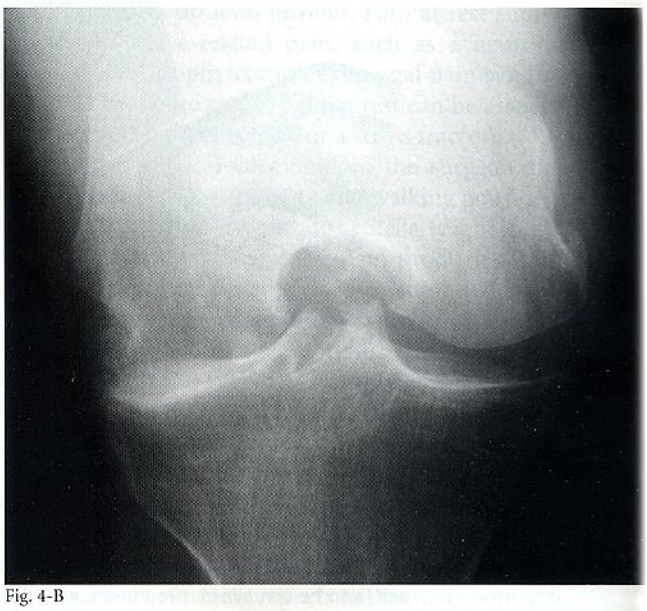

Fig. 4-B

Figs. 4-A and 4-B Arthritis is not apparent on the standard standing anteroposterior radiograph (Fig. 4-A) but is readily apparent on the Rosenberg radiograph (Fig. 4-B).

femoral arthritis, who are generally younger, while an instrument that measures sports activity and instability, such as the Lysholm instrument, may be overly unfavorable to such patients. The Knee Society Score (KSS) Clinical Rating System has been used with some frequency for evaluating patients with knee replacements, but it cannot be self-administered and its reliability and validity have been questioned[31,32]. The International Knee Documentation Committee (IKDC)[33] instrument has shown good validity and reliability in the evaluation of patellofemoral disorders, but it has not been assessed in the context of arthritis[31,34]. The Short Form-36 (SF-36) has been validated for evaluation of quality of life[34,35], but it requires computerized analysis, which limits its clinical accessibility[31].

The Knee Injury and Osteoarthritis Outcome Score (KOOS)[36] (www.koos.nu) is a forty-two-question tool consisting of the reliable WOMAC instrument with the addition of items pertaining to younger, active patients. It has the advantage of being self-administered, with patients able to complete it in approximately ten minutes. Paxton and Fithian recommended its use in the setting of patellofemoral arthritis[31], but it has not yet been utilized with any degree of frequency.

Nonoperative Treatment

Initially, most patients with patellofemoral arthritis can be treated with a nonoperative approach. This includes activity modification, medications, weight control, physical therapy, and possibly bracing, nutritional supplements, and viscosupplementation. Activity modification involves an avoidance of squats, wall-slides, and large steps as well as the admonition that, during exercise, pain should not be "worked through" but avoided altogether. Medications include anti-inflammatory drugs and analgesics, in isolation or in combination. The challenge of physical therapy is to strengthen and stretch the structures about the knee without eliciting pain. Water exercises can be beneficial in that regard. A knee support used in the setting of patellofemoral arthritis should feature an anterior cutout to minimize direct pressure on the patellofemoral joint. Nutritional supplements have not been conclusively found to be helpful in the treatment of arthritis, but substances such as glucosamine appear to be safe[37,38]. Preliminary studies suggest that viscosupplementation is potentially beneficial[39,40].

Operative Treatment

Lateral Retinacular Release

A lateral retinacular release should shift the patellofemoral contact area medially. The operation can therefore be expected to be more successful in patients in whom the medial articular cartilage is intact, but this has not been studied, to our knowledge. It is also not known how far medial the displacement must be for the operation to be successful. The procedure incidentally denervates the patella to a certain extent, and it is unknown to what degree that contributes to the success of the operation when it works.

Aderinto and Cobb[41] reviewed the results at an average of thirty-one months (range, twelve to sixty-five months) after lateral retinacular release in fifty-three patients with patellofemoral arthritis (with or without concomitant femorotibial arthritis). Four patients required a knee replacement within eighteen months. Of the remaining forty-nine patients, twenty-six had isolated patellofemoral arthritis. Thirteen of those twenty-six patients were very satisfied or satisfied with the result of the lateral release, whereas the other thirteen were dissatisfied. Unfortunately, the authors did not differentiate between patients with lateral arthritis and those with global (patellar and trochlear) involvement.

Total Knee Replacement

A traditional total knee replacement, including patellar resurfacing, removes all present and future sources of arthritis. Although early failures continue to be reported[42], the longevity of many knee-replacement designs is excellent and may be substantially greater than the ten to fifteen years that have been reported in the past[43].

In a study of fifty-three patients who had been followed for an average of 7.4 years after total knee replacement with resurfacing of the patella to treat isolated patellofemoral arthritis, Laskin and van Steijn[44] noted an average range of motion of 122°, compared with 117° in a separate cohort of patients with tricompartmental disease, with 81% (forty-three) of the fifty-three patients having a good-to-excellent result.

Parvizi et al.[45] evaluated the results of thirty-one knee replacements in twenty-four patients at an average of five years. They noted that twenty-one patients required a lateral retinacular release and three more required a more extensive realignment.

In a study of the results of thirty-three replacements in twenty-seven patients who had primarily patellofemoral arthritis, Mont et al.[46] reported twenty-eight excellent results, one good result, and one poor result at a mean of eighty-one months postoperatively. The mean Knee Society objective score increased from 50 points preoperatively to 93 points postoperatively.

Resurfacing of the patella in total knee replacement is a controversial issue, even when the patella is arthritic. A number of surgeons have reported routinely leaving the patella unresurfaced during knee replacement surgery. Thompson et al. took the concept to the extreme when they performed thirty-three total knee replacements without patellar resurfacing in thirty-one patients with isolated patellofemoral arthritis in whom the pain, by definition, could have come only from the patellofemoral joint[47]. At twenty months postoperatively, twenty-one knees were pain-free and twelve knees were occasionally painful. The average range of flexion was 104°. None of the patients required revision surgery.

Despite the success of total knee arthroplasty, many surgeons consider it to be too big a sacrifice of healthy tissue and too great a surgical dissection for a patient with disease involving mainly one compartment.

Anterior Transfer of the Tibial Tuberosity

If patellofemoral pain is postulated to be the result of loads applied to deficient cartilage, it stands to reason that a dimi-

nution of those loads could lead to pain relief. This has been the theory behind operations that relocate the tibial tuberosity to a more anterior position. However, the size of the contact area on which these loads are applied has to be considered when judging subchondral stresses. Indeed, as noted by Lewallen et al.[48], a diminution of forces may not necessarily lead to a reduction of the stresses. Therefore, studies that only evaluate forces[49] may not provide clinically relevant data.

Maquet[50] was the first to develop a procedure that moves the tibial tuberosity anteriorly, with his eponymous operation that elevates the tuberosity by 2.5 cm. On the basis of in vitro studies, Ferguson et al.[51] later proposed a variation on Maquet's operation, whereby the tibial tuberosity was elevated just 0.5 in (1.27 cm). Schepsis et al.[52] recommended an elevation of 1.6 to 1.8 cm to compensate for the expected settling of the construct. Subsequent investigators have recommended elevations as low as 1.25 cm[53] and even 1 cm[54,55] on the basis of in vitro considerations. Ferrandez et al.[55] noted that elevation of the tibial tuberosity can paradoxically increase stresses on the proximal portion of the patella, particularly when it is elevated >1 cm. Using in vitro measurements, both Nakamura et al.[54] and Ferrandez et al. found an elevation of >1 cm to be counterproductive with regard to patellofemoral stresses.

The Maquet operation has been reportedly associated with a number of complications, most notably skin necrosis, cracking of the osteotomy fragment, patellar tendinitis, and the development of a painful prominence at the level of the tibial tuberosity[52]. These problems have largely been addressed by lengthening of the osteotomy fragment that is elevated, as this minimizes the angulation required for a given elevation.

Because Maquet's operation has been used for a wide variety of patellofemoral conditions and because the results have not always been correlated with the etiology of the pain or the specific location of the arthritis, the clinical results of the operation for patellofemoral arthritis can be difficult to ascertain. Heatley et al.[56] noted that, of fourteen knees treated with a Maquet operation for patellofemoral arthritis, six were rated as good to excellent, three were rated as fair, and five were rated poor at six years postoperatively. Jenny et al.[57] evaluated sixty-five patients who had undergone a Maquet procedure for a variety of conditions and found that the forty-eight patients with patellofemoral arthritis had the best results at an average of eleven years. In neither study was the exact location of the arthritis within the patellofemoral joint specified. Division of the patients into subgroups according to the location of the chondral lesions would have been useful.

Engebretsen et al.[58] reported on thirty-eight patients treated with the Maquet procedure. Of thirty-three patients who were available for follow-up at a mean of five years, ten had improvement, seventeen had no change, and six were worse off. The patients with improvement were noted to have "Grade III and IV" cartilage changes primarily involving the lateral facet.

Over the last twenty years, Maquet's operation has diminished in popularity in Europe[59], with some surgeons actually reversing the procedure[23]. However, a variation on the Maquet procedure—anteromedial displacement of the tibial tuberosity—increased in popularity in the United States over that same period of time.

Anteromedial Transfer of the Tibial Tuberosity

The anteromedial tibial tuberosity osteotomy, as described by Fulkerson et al.[60], is a modification of the Maquet operation. The procedure is carried out with an oblique osteotomy of the tibial tuberosity that is sloped in an anteromedial-to-posterolateral direction. The tibial tuberosity is transferred both medially and anteriorly, with the relative proportion of each transfer being determined by the slope of the cut. A relatively flat, horizontal cut across the tibial tuberosity leads to mostly medial displacement, whereas a more vertical cut leads to greater vertical displacement. A 45° cut leads to equal medial and vertical displacements.

This operation has the disadvantage of not allowing the same amount of anterior displacement as Maquet's procedure permits, and it displaces the tibial tuberosity medially even in patients in whom the need for such medialization is unclear (for example, patients with a normal quadriceps [Q] angle)[61]. Medial displacement of the tuberosity in this setting may increase the medial femorotibial forces, resulting in pain in that compartment.

This procedure does offer a number of advantages. A single osseous cut achieves both anterior and medial displacement in patients who need this combined effect. A bone wedge is not required at the osteotomy site to maintain the displacement. If the screws used for fixation of the shingle are oriented perpendicular to the plane of the osteotomy, both the drill and the screws will be oriented toward the medial aspect of the posterior part of the tibia and the popliteal space, where injury to the popliteal artery or vein is unlikely[62]. Most importantly, in the setting of patellofemoral arthritis this operation shifts the patellofemoral contact area medially, an advantageous displacement when the arthritis is located on the lateral aspect of the patella.

This osteotomy presents technical pitfalls. It requires two cuts. The first cut involves all but the most proximal portion of the tibial tuberosity. That cut is angled in an anteromedial-to-posterolateral direction, with care taken to protect both the anterior tibial artery and the deep peroneal nerve posteriorly. The second cut begins at the most proximal and lateral aspect of the first cut and is oriented toward the most proximal portion of the tibial tuberosity. If the surgeon fails to carry out this second cut and chooses instead to carry the first cut all of the way to the top of the tuberosity, the cut will involve a large part of the proximal tibial metaphysis.

If the tibial tuberosity were displaced 11 mm along a 45° degree plane, which is a substantial displacement, this would lead to 8 mm of medial displacement and 8 mm of anterior displacement. Ateshian and Hung[7] calculated that this would result in only a 10% reduction in stress. This would explain why the procedure is not well suited for the treatment of global arthritis of the patellofemoral joint[63], although the correlation between clinical success and stress reduction has yet to be established. Moreover, an 8-mm anteromedial displacement of the tibial tu-

berosity would lead to a 4.5-mm medial displacement of the patellofemoral contact area[7], which, in some cases, may be enough to provide clinical improvement. Greater anterior advancement is not necessarily beneficial. For example, Takeuchi et al.[64] performed an oblique osteotomy (with a 70 × 15-mm shingle) on seven specimens, and, using pressure-sensitive film, found that an elevation of 10 mm provided greater stress (force/area) reduction than an elevation of 20 mm. Indeed, the diminished forces at elevations of 20 mm were largely (and negatively) offset by the diminution in contact area.

Pidoriano et al.[63] correlated the results of this procedure with the specific location of the arthritic lesions. They noted the best results in patients with arthritis isolated to the lateral portion of the patella, even when there was a complete loss of articular cartilage at that site, and the worst results in patients who had diffuse involvement of the patella, extensive involvement of the trochlea, diseased cartilage at the proximal portion of the patella, and crush injuries[65].

Complications associated with this operation include postoperative fracture of the tibial shaft and nonunion of the osteotomy site. The osteotomy incorporates a substantial portion of the proximal tibial cortex, thus greatly diminishing the tibia's ability to withstand torque. Stetson et al.[66] reported that six patients and Bellemans et al.[67] reported that four patients sustained a fracture of the tibia at the distal junction of the osteotomized tibial tuberosity and the tibial shaft. All fractures occurred as the patients progressed to full weight-bearing status. Bellemans et al. recommended that patients remain nonweight-bearing for eight weeks. In the series reported by Stetson et al., two of the six fractures occurred after eight weeks, and the authors therefore recommended that full weight-bearing not be allowed until there was radiographic evidence of osseous healing.

The screw heads may be palpable and tender, and one or both screws may need to be removed after healing of the osteotomy site. Removing a partially threaded cancellous screw can be difficult as the threads may not be able to cut back through bone that has grown along the nonthreaded portion of the screw, and use of a fully threaded screw may be advisable.

Patellofemoral Replacement

The practice of resurfacing the patella in patients who have patellofemoral arthritis predates total knee replacement by approximately ten years. McKeever[68] was, to our knowledge, the first to report such an operation when he described fixing a metallic implant to the undersurface of the patella by way of a transverse screw. Vermeulen et al.[69] reported that, eight to ten years following use of the McKeever prosthesis in nine women (age range, forty-six to seventy years; average age, sixty-one years), no patient had required a reoperation; pain and function scores were not reported. In 1979, Pickett and Stoll[70] reported that, one to twenty-two years following forty-six McKeever operations, thirty-nine had a "satisfactory" result as determined by both the patient and the surgeon. Harrington[71] found that, at five years after McKeever patellar resurfacing, seventeen of twenty-four patients had a good or excellent result. The poor results occurred in patients who had signs of osteoarthritis in other parts of the knee.

In 1975, Aglietti et al.[72] introduced a dome-shaped cobalt-chromium-molybdenum patellar component that was identical in shape to the patellar button of their total knee replacement. They did not report the results of clinical follow-up. Worrell designed a cobalt-chromium device and reported short-term follow-up results in 1979[73] and then again reported results in 1986[74]. Of fourteen knees in thirteen patients (eighteen to thirty-eight years of age) followed for a mean of five and a half years (range, one to eight years), two had an excellent result; one, a good result; seven, a fair result; and four, a poor result. The best results were in patients over the age of forty years who had "extremely poor quadriceps function." The implant has not been reported on by other investigators, to our knowledge.

The concept of a metallic implant articulating with the cartilaginous trochlea has been unappealing to the orthopaedic community because of concerns about harming an intact trochlea or, conversely, not addressing chondral lesions already present in the trochlea.

In 1979, Lubinus[75] and Blazina et al.[76] introduced separately the concept of a patellofemoral replacement whereby both the patella and the trochlea were resurfaced. Despite some confusion in the literature[46], this operation is separate and distinct from a simple patellar resurfacing. The procedure requires less surgical dissection than a total knee replacement, removes less bone, preserves the femorotibial compartments as well as the cruciate ligaments, does not necessitate blood transfusion, and can potentially be less expensive.

Patellofemoral replacement surgery has not been widely accepted. The original descriptions of the procedure did not include strict criteria, technical pitfalls were not yet appreciated, and little emphasis was placed on realignment of the extensor mechanism of the knee. Consequently, reports pertaining to the earliest designs showed disappointing results. In Europe this led to efforts to redesign the implant and improve the operative technique, and in the United States most surgeons simply abandoned the procedure.

The literature of the last fifteen years has been far more encouraging. Cartier et al.[77] reported the results at an average of four years after patellofemoral replacements in seventy-two patients, thirty-six of whom had a concomitant femorotibial unicompartmental replacement and one of whom also underwent a tibial osteotomy. Sixty-one patients (85%) had a good-to-excellent result according to the Mansat (0 to 20-point) scale[78]. Another five patients (7%) had a good-to-excellent result after undergoing a remedial procedure (additional patellar realignment and exchange of the patellar button for a smaller size). In 1995, Argenson et al. reported the results of sixty-six replacements reviewed at an average of 5.5 years[79]. Dividing their results by etiology, they noted a good result in twenty of twenty-two patients with malalignment and dysplasia, nineteen of twenty patients with posttraumatic arthritis, and seventeen of twenty-four patients with arthritis of unknown etiology.

In 1996, Krajca-Radcliffe and Coker[80] reported a good-to-

excellent result in fifteen of sixteen patients followed for an average of 5.8 years after patellofemoral replacement. Mertl et al.[81] reviewed the outcomes of fifty patellofemoral replacements at an average of three years (with twenty-two followed for at least four years) and, using the Guepar rating tool[82], found 34% (seventeen) very good, 48% (twenty-four) good, and 18% (nine) poor results. Of the nine failures, five pertained to the femorotibial compartments; two, to a complex regional pain syndrome; one, to an infection; and one was in a patient with a Workers' Compensation claim whose pain remained unresolved. Arnbjornsson and Ryd[83] found that, at seven years after patellofemoral replacement, 75% (eighty-five) of 113 patients were satisfied with the result, 58% (sixty-six) of the 113 walked without assistive devices, and 44% (fifty) of the 113 had no or only occasional knee pain. Predictably, they found the poorest results in patients who had the nonspecific diagnosis of chondromalacia.

De Cloedt et al.[84] followed forty-five patients for three to twelve years after patellofemoral replacement and found that only 43% (nine) of twenty-one patients with arthritis and no malalignment or dysplasia had a good result, with the main cause of failure being degeneration of the femorotibial compartments. In contrast, 83% (twenty) of twenty-four patients with so-called patellofemoral instability and/or trochlear dysplasia had a good result. Kooijman et al.[85] followed forty-five patients for ten to twenty-one years after patellofemoral arthroplasty. Fifteen patients required another operation (most commonly a soft-tissue operation such as a lateral retinacular release) soon after the index procedure, and twelve underwent either a tibial osteotomy or a total knee replacement at an average of fifteen years. However, two-thirds (thirty-three) of the forty-five patients still had the patellofemoral replacement at the time of final follow-up (at an average of seventeen years).

The poor results reported after patellofemoral replacement have a common theme: failure to appreciate present or incipient femorotibial arthritis. Arthritis is more likely to develop in the remainder of the knee in a patient with an incomplete evaluation and in a patient in whom the patellofemoral arthritis does not have a clear origin, such as malalignment, dysplasia, or trauma.

Autologous Chondrocyte Implantation

Autologous chondrocyte implantation involves harvest of articular cartilage from a portion of the patient's femoral condyle, culture of the chondrocytes to multiply their number, and reimplantation of the chondrocytes into the chondral defect(s) that is (are) thought to be the source of pain. Although this technology has been used mainly for isolated defects of the femoral condyle, attempts have been made to apply it to the patellofemoral joint. Early attempts in a small number of patients did not yield good results[86]. This was thought to be related to the unfavorable mechanics of the patellofemoral joint[87,88]. Indeed, both sides of the patellofemoral articulation are subject to shear stresses with every flexion-extension cycle. The central portion of the patella is twice subject to shear during the cycle: at a knee flexion angle of approximately 45° and again at 120°[12].

Recently, Minas and Bryant[89] reported more favorable results with autologous chondrocyte implantation. They investigated a group of forty-five patients who had patellofemoral arthritis, with or without femorotibial arthritis. Eight patients had isolated patellar arthritis, nine had trochlear arthritis, four demonstrated patellar and trochlear arthritis, and the remainder exhibited arthritis in two or more compartments. The authors noted that, at an average of two years postoperatively, the patients with patellar arthritis, trochlear arthritis, and "patella plus trochlea plus weight-bearing condyles" (involvement of both the patellar and the trochlear side of the patellofemoral articulation as well as of the weight-bearing portion of one or both femoral condyles) "all had marked improvement in pain relief and function." There were eight graft failures in the patellofemoral compartment. Minas and Bryant noted clinical failures in five of eleven patients with a Workers' Compensation claim.

Autologous chondrocyte implantation is expensive but may eventually be cost-effective if it provides long-term pain relief. Examining costs per quality-adjusted life-year, Clar et al.[90] attempted to compare the cost-effectiveness of autologous chondrocyte implantation procedures in the knee with microfracture and mosaicplasty operations, but they found the results to be inconclusive because of a lack of sufficient long-term data. Derrett et al.[91] also investigated the costs per quality-adjusted life-year of both autologous chondrocyte implantation and mosaicplasty. They found that both operations fell below "an implicit English funding threshold"—in other words, they were not (yet) cost-effective according to the available follow-up data.

Longer follow-up and clinical trials comparing autologous chondrocyte implantation with other options for treatment of patellofemoral arthritis are needed before this option can be recommended as a standard procedure.

Patellectomy

A patellectomy is a resection arthroplasty of the patellofemoral joint. The term *patellectomy* encompasses a number of operations, the end result of which is the removal of the patella. These operations differ only in the way that the peripatellar soft tissues are managed. Patellectomy was a common operation in the early to mid-twentieth century, when a number of structures about the knee, including the patella and menisci, were thought to be expendable. Its appeal lies in its perceived relative simplicity compared with other procedures. It can be reasoned that removal of the patellar half of a painful patellofemoral joint will cause the pain to disappear. However, the pain from an arthritic trochlea cannot be relieved by a patellectomy, and removal of the patella greatly diminishes the lever arm of the extensor mechanism of the knee. This can lead to extensor weakness and/or a so-called extensor lag, whereby the patient is incapable of completely straightening the knee.

The popularity of the procedure has gone through cycles. In 1909, Heineck[92] condemned it, stating that, on the basis of his experience with five patients, "its removal is invariably followed by impairment of power, by some functional

loss." Brooke[93], in 1937, reported good results in thirty cases, and Hey Groves[94] supported Brooke's opinion that the procedure was beneficial. In 1948, McFarland[95] went so far as to recommend the procedure for simple recurrent patellar dislocation. However, in 1949, Scott[96] reviewed a series of seventy-one patellar fractures treated with patellectomy and found that 60% of patients reported so-called giving-way of the knee and 90% of patients still had pain. Since then, the literature has been inconclusive regarding this procedure.

In 1969, Castaing et al.[97] reported that forty-six of sixty-one patients had a good-to-excellent result at an average of five years after a patellectomy. The patellectomy was carried out with use of a vertical incision over the patella. A nearly full-thickness flap of quadriceps tendon was turned down and was sutured into the patellar tendon, and the medial and lateral retinacula were sutured over this turn-down construct. In a subset of seventeen patients with arthritis, just six patients had a good-to-excellent result, with the poorest results found in those with femorotibial disease. Overall, quadriceps strength, the active range of motion, and knee stability were judged to be acceptable. Stair descent tended to be a source of problems. Heterotopic ossification about the patellectomy site (considered to be "patellar regeneration" by the authors) was noted in two patients, but it had no correlation with results. Recovery tended to be long, and a number of patients noted continued improvement over the follow-up period.

Compere et al.[98] reported on twenty-nine knees followed for an average of approximately seven years after patellectomy. The patients were young (average age, 43.5 years) and presented with various degrees of arthritis. The fibers at the dorsum of the patella were maintained while the patella was everted and enucleated. The medial and lateral borders of the quadriceps and patellar tendons were sutured together to fashion a tube. The vastus medialis was advanced and sutured onto this tube. Ninety percent (twenty-six) of the twenty-nine knees were rated as having a good-to-excellent result. "Symptomatic calcification in the patellar tendon" developed in one patient; it was surgically removed, and the patient eventually had an excellent result. De la Caffinière[99] noted good results in a cohort of seventy young patients (thirty to sixty years of age) with patellofemoral arthritis. Addressing the issue of quadriceps weakness and extensor lag following patellectomy procedures, he noted that final quadriceps strength could not be assessed less than two years following the operation. Baker and Hughston[100] noted that nineteen of twenty patients with arthritis of the knee were satisfied at an average of fourteen years following treatment with the Miyakawa technique[101], which requires that a partial-thickness strip of quadriceps tendon be turned down over the void left by the patella. In addition, the vastus lateralis and vastus medialis are advanced, crossed over each other, and attached to the quadriceps tendon.

In a more recent review, Lennox et al.[102] found the poorest results in their patients who underwent a patellectomy for arthritis. (Not all of their patients underwent the patellectomy for that indication.) They reported a good result in only 54% (twelve) of twenty-two patients with arthritis, with 27% (six) of the twenty-two patients reporting that they felt worse than they had preoperatively. This was a retrospective analysis of patients who had been operated on twelve to forty-eight years earlier, with the charts having been culled from hospital records. The evaluation was carried out mostly by telephone. The article does not name or describe the surgical technique(s).

A shortcoming of all of the above studies is a lack of description of the anatomic location of the arthritis. It is not clear, for example, what percentage of patients had arthritis limited to the patella or how often arthritis was present on both the patella and the trochlea.

We believe that a patellectomy can relieve symptoms and improve function when the advancement of soft tissues adequately compensates for the void left by the patellectomy. Although logic would dictate that patellectomies performed for the treatment of patellofemoral arthritis would be more successful when the arthritis is limited to the patella, this has not been studied, to our knowledge. A major drawback of a patellectomy is that, for all practical purposes, it is irreversible, although perhaps less so than other resection arthroplasties.

Removal of Subchondral Bone, Facetectomy, Thinning, and Denervation

These infrequently performed procedures approach the problem of patellofemoral arthritis in a manner that, in the twenty-first century, is considered unconventional.

In a procedure termed *spongialization* by its originators (Ficat et al.[103]), the subchondral bone is removed down to cancellous (spongy) bone. The operation was also described by Marmor[104] and is still used by some in lieu of patellar resurfacing during total knee replacement arthroplasty[105].

When the patellofemoral arthritis is limited to the lateralmost portion of the compartment, consideration can be given to removing 1 to 1.5 cm from the lateral aspect of the patella (a so-called facetectomy). Yercan et al.[106] followed eleven patients for an average of eight years after such a procedure and noted a significant increase in the average pain score ($p = 0.04$) and in the average Knee Society score ($p = 0.02$) (based on the findings of a physical examination)[107]. The average Knee Society functional score (based on walking and stair-climbing) also improved.

In order to diminish the stresses on the patellofemoral joint, bone can be removed from the center of the patella to decrease its thickness. Both the removal of the layer and the reattachment of the two remaining portions may be technically difficult, especially since care must be taken not to further damage the articular surface. Nerubay and Katnelson[108] performed the procedure on fifteen patients who had demonstrated patellar malalignment and followed them for an average of three years. Twelve patients had a good-to-excellent result. Vaquero and Arriaza[109] used a double saw to remove 7 mm of bone from the center of the patella and noted a diminution of patellofemoral stresses when they applied Fuji film to the patellofemoral joint. Following this operative procedure, there may not be much osseous bed left for a prosthetic replacement if one is needed at a later time.

The patella is innervated by multiple superficial sensory nerves, including the medial cutaneous nerve of the thigh, the lateral femoral cutaneous nerve, the medial and lateral retinacular nerve, and the anterior femoral cutaneous nerve[110]. Division of these nerves can diminish pain emanating from the patella but is likely to be less effective for trochlear lesions. No formal study of surgical denervation has been carried out in the specific setting of patellofemoral arthritis, to our knowledge.

Future Considerations

If autologous chondrocyte implantation can be used to fill discrete defects, it is possible that similar technology could be utilized for larger surfaces. Ateshian and Hung[7] investigated the possibility of resurfacing the entire patellar articulation with anatomically shaped molds to contour chondrocyte-seeded gels into the desired shape. They found that dynamic loading of the construct greatly increased its strength, to the point where the mechanical properties of the articular cartilage approached those of the native tissue. To anchor the cartilage into bone, it may be feasible to engineer cartilage cells that are already anchored into an osseous substrate. Ateshian and Hung experimentally used bovine bone for this purpose. These large constructs pose challenges to nutrient diffusion in the cartilage that will need to be solved before large, viable areas of articular cartilage can be produced.

Overview

A number of challenges remain in the field of patellofemoral arthritis. In order to improve investigations of treatments, the orthopaedic community needs to accept a validated outcome tool. The term *patellofemoral arthritis* itself requires greater anatomic precision, as arthritis localized to one portion of the patellofemoral compartment may behave differently from global patellar and trochlear arthritis. Clinically, the challenges to the surgeon remain the identification of patients whose symptoms are truly the result of isolated patellofemoral arthritis and the selection of a viable surgical operation for those patients. The lack of uniform reporting makes it difficult to recommend one procedure over another at this time. Operations that shift the patellofemoral contact area medially are recommended for young patients with arthritis that is limited to the lateral aspect of the patella, whereas joint replacement surgery remains the best option for older patients who have diffuse arthritis involving both the patella and the trochlea.

Ronald P. Grelsamer, MD
Mount Sinai Medical School, 5 East 98th Street, Box 1188, New York, NY 10029. E-mail address for R.P. Grelsamer: RGrelsamer@aol.com

Drew A. Stein, MD
927 49th Street, Brooklyn, NY, 11219

The authors did not receive grants or outside funding in support of their research for or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

doi:10.2106/JBJS.E.01394

References

1. Oberlander MA, Baker CL, Morgan BE. Patellofemoral arthrosis: the treatment options. Am J Orthop. 1998;27:263-70.

2. Davies AP, Vince AS, Shepstone L, Donell ST, Glasgow MM. The radiologic prevalence of patellofemoral osteoarthritis. Clin Orthop Relat Res. 2002; 402:206-12.

3. Utting MR, Davies G, Newman JH. Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? Knee. 2005;12:362-5.

4. McAlindon TE, Snow S, Cooper C, Dieppe PA. Radiographic patterns of osteoarthritis of the knee joint in the community: the importance of the patellofemoral joint. Ann Rheum Dis. 1992;51:844-9.

5. Mow VC, Hayes WC. Basic orthopaedic biomechanics. 2nd ed. Philadelphia: Lippincott-Raven; 1997.

6. Mow VC, Kuei SC, Lai WM, Armstrong CG. Biphasic creep and stress relaxation of articular cartilage in compression? Theory and experiments. J Biomech Eng. 1980;102:73-84.

7. Ateshian GA, Hung CT. Patellofemoral joint biomechanics and tissue engineering. Clin Orthop Relat Res. 2005;436:81-90.

8. Spector TD, MacGregor AJ. Risk factors for osteoarthritis: genetics. Osteoarthritis Cartilage. 2004;12 Suppl A:S39-44.

9. Grelsamer RP, Stein DA. Rotational malalignment of the patella. In: Fulkerson JP, editor. Common patellofemoral problems. American Academy of Orthopaedic Surgeons; 2005. p 19-28.

10. Grelsamer RP. Patellar malalignment. J Bone Joint Surg Am. 2000;82: 1639-50.

11. McAlindon T, Zhang Y, Hannan M, Naimark A, Weissman B, Castelli W, Felson D. Are risk factors for patellofemoral and tibiofemoral knee osteoarthritis different? J Rheumatol. 1996;23:332-7.

12. Grelsamer RP, Weinstein CH. Applied biomechanics of the patella. Clin Orthop Relat Res. 2001;389:9-14.

13. Cohen ZA, Roglic H, Grelsamer RP, Henry JH, Levine WN, Mow VC, Ateshian GA. Patellofemoral stresses during open and closed kinetic chain exercises. An analysis using computer simulation. Am J Sports Med. 2001;29:480-7.

14. Ficat P, Ficat C, Bailleux A. [External hypertension syndrome of the patella. Its significance in the recognition of arthrosis]. Rev Chir Orthop Reparatrice Appar Mot. 1975;61:39-59. French.

15. Merchant AC, Mercer RL. Lateral release of the patella. A preliminary report. Clin Orthop Relat Res. 1974;103:40-5.

16. Putz R, Muller-Gerbl M, Eckstein F, Benedetto K. Are there any correlations between superficial cartilaginous alterations and subchondral bone density (CT-OAM) in the femoropatellar joint? Orthop Trans. 1991;15:497.

17. Eckstein F, Muller-Gerbl M, Putz R. [The distribution of cartilage degeneration of the human patella in relation to individual subchondral mineralization]. Z Orthop Ihre Grenzgeb. 1994;132:405-11. German.

18. Iwano T, Kurosawa H, Tokuyama H, Hoshikawa Y. Roentgenographic and clinical findings of patellofemoral osteoarthrosis. With special reference to its relationship to femorotibial osteoarthrosis and etiologic factors. Clin Orthop Relat Res. 1990;252:190-7.

19. Witonski D, Wagrowska-Danielewicz M. Distribution of substance-P nerve fibers in the knee joint in patients with anterior knee pain syndrome. A preliminary report. Knee Surg Sports Traumatol Arthrosc. 1999;7:177-83.

20. Niskanen RO, Paavilainen PJ, Jaakkola M, Korkala OL. Poor correlation of clinical signs with patellar cartilaginous changes. Arthroscopy. 2001;17:307-10.

21. Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. Clin Orthop Relat Res. 2005;436:100-10.

22. Insall JN. Foreword. In: Scuderi GR. The patella. New York: Springer; 1995.

23. Cartier P, Sanouiller JL, Khefacha A. Long-term results with the first patellofemoral prosthesis. Clin Orthop Relat Res. 2005;436:47-54.

24. Merchant AC, Mercer RL, Jacobsen RH, Cool CR. Roentgenographic analysis of patellofemoral congruence. J Bone Joint Surg Am. 1974;56:1391-6.

25. Maldague B, Malghem J. Apport du cliché de profil du genou dans le dépistage des instabilités rotuliennes. Rapport préliminaire. [Significance of the radiograph of the knee profile in the detection of patellar instability. Preliminary report]. Rev Chir Orthop Reparatrice Appar Mot. 1985;71 Suppl 2:5-13. French.

26. Rosenberg TD, Paulos LE, Parker RD, Coward DB, Scott SM. The forty-five-degree posteroanterior flexion weight-bearing radiograph of the knee. J Bone Joint Surg Am. 1988;70:1479-83.

27. Kotani H, Ishisaka N, Furu M, Miki T, Ueo T. A new plain radiography method using the optimal angle of knee flexion for assessing early degeneration of the knee joint. J Arthroplasty. 2005;20:614-7.

28. Corpe RS, Engh GA. A quantitative assessment of degenerative changes acceptable in the unoperated compartments of knees undergoing unicompartmental replacement. Orthopedics. 1990;13:319-23.

29. Steere AC, Malawista SE, Snydman DR, Shope RE, Andiman WA, Ross MR, Steele FM. Lyme arthritis: an epidemic of oligoarticular arthritis in children and adults in three Connecticut communities. Arthritis Rheum. 1977;20:7-17.

30. Remy F, Besson A, Gougeon F, Migaud H, Duquenoy A. Evaluation fonctionelle de l'instabilite femoro-patellaire par un score 100 points. [Functional evaluation of patello-femoral instability using a 100 point scale]. Rev Chir Orthop Reparatrice Appar Mot. 1999;85(Suppl III):92-3. French.

31. Paxton EW, Fithian DC. Outcome instruments for patellofemoral arthroplasty. Clin Orthop Relat Res. 2005;436:66-70.

32. Lingard EA, Katz JN, Wright RJ, Wright EA, Sledge CB; Kinemax Outcomes Group. Validity and responsiveness of the Knee Society Clinical Rating System in comparison with the SF-36 and WOMAC. J Bone Joint Surg Am. 2001;83:1856-64.

33. Irrgang JJ, Anderson AF, Boland AL, Harner CD, Kurosaka M, Neyret P, Richmond JC, Shelborne KD. Development and validation of the International Knee Documentation Committee Subjective Knee Form. Am J Sports Med. 2001;29:600-13.

34. Zarins B. Are validated questionnaires valid? J Bone Joint Surg Am. 2005;87:1671-2.

35. Bartlett W, Gooding CR, Carrington RW, Briggs TW, Skinner JA, Bentley G. The role of the Short Form 36 Health Survey in autologous chondrocyte implantation. Knee. 2005;12:281-5.

36. Roos EM, Roos HP, Ekdahl C, Lohmander LS. Knee injury and Osteoarthritis Outcome Score (KOOS)—validation of a Swedish version. Scand J Med Sci Sports. 1998;8:439-48.

37. Clegg DO, Reda DJ, Harris CL, Klein MA, O'Dell JR, Hooper MM, Bradley JD, Bingham CO 3rd, Weisman MH, Jackson CG, Lane NE, Cush JJ, Moreland LW, Schumacher HR Jr, Oddis CV, Wolfe F, Molitor JA, Yocum DE, Schnitzer TJ, Furst DE, Sawitzke AD, Shi H, Brandt KD, Moskowitz RW, Williams HJ. Glucosamine, chondroitin sulfate, and the two in combination for painful knee osteoarthritis. N Engl J Med. 2006;354:858-60.

38. Anderson JW, Nicolosi RJ, Borzelleca JF. Glucosamine effects in humans: a review of effects on glucose metabolism, side effects, safety considerations and efficacy. Food Chem Toxicol. 2005;43:187-201.

39. Clarke S, Lock V, Duddy J, Sharif M, Newman JH, Kirwan JR. Intra-articular hylan G-F 20 (Synvisc) in the management of patellofemoral osteoarthritis of the knee (POAK). Knee. 2005;12:57-62.

40. Torrance GW, Raynauld JP, Walker V, Goldsmith CH, Bellamy N, Band PA, Schultz M, Tugwell P; Canadian Knee OA Study Group. A prospective randomized, pragmatic, health outcomes trial evaluating the incorporation of hylan G-F 20 into the treatment paradigm for patients with knee osteoarthritis (part 2 of 2): economic results. Osteoarthritis Cartilage. 2002;10:518-27.

41. Aderinto J, Cobb AG. Lateral release for patellofemoral arthritis. Arthroscopy. 2002;18:399-403.

42. Sugimoto K, Iwai M, Okahashi K, Kaneko K, Tanaka M, Takakura Y. Premature failure of the polyethylene tibial bearing surface of the Interax knee arthroplasty. J Arthroplasty. 2005;20:658-63.

43. Rodriguez JA, Bhende H, Ranawat CS. Total condylar knee replacement: a 20-year followup study. Clin Orthop Relat Res. 2001;388:10-7.

44. Laskin RS, van Steijn M. Total knee replacement for patients with patellofemoral arthritis. Clin Orthop Relat Res. 1999;367:89-95.

45. Parvizi J, Stuart MJ, Pagnano MW, Hanssen AD. Total knee arthroplasty in patients with isolated patellofemoral arthritis. Clin Orthop Relat Res. 2001;392:147-52.

46. Mont MA, Haas S, Mullick T, Hungerford DS. Total knee arthroplasty for patellofemoral arthritis. J Bone Joint Surg Am. 2002;84:1977-81.

47. Thompson NW, Ruiz AL, Breslin E, Beverland DE. Total knee arthroplasty without patellar resurfacing in isolated patellofemoral osteoarthritis. J Arthroplasty. 2001;16:607-12.

48. Lewallen DG, Riegger CL, Myers ER, Hayes WC. Effects of retinacular release and tibial tubercle elevation in patellofemoral degenerative joint disease. J Orthop Res. 1990;8:856-62.

49. Singerman R, White C, Davy DT. Reduction of patellofemoral contact forces following anterior displacement of the tibial tubercle. J Orthop Res. 1995;13:279-85.

50. Maquet P. Considerations biomechaniques sur l'arthrose du genou.Un traitement biomechanique de l'arthrose femoropatellaire: l'avancement du tendon rotulien. [A biomechanical treatment of femoro-patellar arthrosis: advancement of the patellar tendon]. Rev Rhum Mal Osteoartic. 1963;30:779-83. French.

51. Ferguson AB Jr, Brown TD, Fu FH, Rutkowski R. Relief of patellofemoral contact stress by anterior displacement of the tibial tubercle. J Bone Joint Surg Am. 1979;61:159-66.

52. Schepsis AA, DeSimone AA, Leach RE. Anterior tibial tubercle transposition for patellofemoral arthrosis. Am J Knee Surg. 1994;7:13-20.

53. Retaillaud JL, Darmana R, Devallet P, Mansat M, Morucci JP. [Experimental biomechanical study of the advancement of tibial tuberosity]. Rev Chir Orthop Reparatrice Appar Mot. 1989;75:513-23.

54. Nakamura N, Ellis M, Seedhom BB. Advancement of the tibial tuberosity. A biomechanical study. J Bone Joint Surg Br. 1985;67:255-60.

55. Ferrandez L, Usablaga J, Yubero J, Sagarra J, de No L. An experimental study of the redistribution of patellofemoral pressures by the anterior displacement of the anterior tuberosity of the tibia. Clin Orthop Relat Res. 1989;238:183-9.

56. Heatley FW, Allen PR, Patrick JH. Tibial tubercle advancement for anterior knee pain. A temporary or permanent solution. Clin Orthop Relat Res. 1986;208:215-24.

57. Jenny JY, Sader Z, Henry A, Jenny G, Jaeger JH. Elevation of the tibial tubercle for patellofemoral pain syndrome. An 8- to 15-year follow-up. Knee Surg Sports Traumatol Arthrosc. 1996;4:92-6.

58. Engebretsen L, Svenningsen S, Benum P. Advancement of the tibial tuberosity for patellar pain. A 5-year follow-up. Acta Orthop Scand. 1989;60:20-2.

59. Henderson I, Francisco R. Treatment outcome of extensor realignment for patellofemoral dysfunction. Knee. 2005;12:323-8.

60. Fulkerson JP, Becker GJ, Meaney JA, Miranda M, Folcik MA. Anteromedial tibial tubercle transfer without bone graft. Am J Sports Med. 1990;18:490-7.

61. Goutallier D, Bernageau J. Le point sur la TA-GT. The AT-TG Distance. In: D Goutallier, editor. Pathologie fémoro-patellaire. Vol. 71. Paris: Expansion Scientifique; 1999. p 175-82.

62. Shetty AA, Tindall AJ, Nickolaou N, James KD, Ignotus P. A safe zone for the passage of screws through the posterior tibial cortex in tibial tubercle transfer. Knee. 2005;12:99-101.

63. Pidoriano AJ, Weinstein RN, Buuck DA, Fulkerson JP. Correlation of patellar articular lesions with results from anteromedial tibial tubercle transfer. Am J Sports Med. 1997;25:533-7.

64. Takeuchi R, Koshino T, Saito T, Suzuki E, Sakai N. Patello-femoral contact area and compressive force after antero-medial displacement of tibial tuberosity in amputated knees. Knee. 1999;6:109-14.

65. Fulkerson JP. Alternatives to patellofemoral arthroplasty. Clin Orthop Relat Res. 2005;436:76-80.

66. Stetson WB, Friedman MJ, Fulkerson JP, Cheng M, Buuck D. Fracture of the proximal tibia with immediate weightbearing after a Fulkerson osteotomy. Am J Sports Med. 1997;25:570-4.

67. Bellemans J, Cauwenberghs F, Brys P, Victor J, Fabry G. Fracture of the proximal tibia after Fulkerson anteromedial tibial tubercle transfer. A report of four cases. Am J Sports Med. 1998;26:300-2.

68. McKeever DC. Patellar prosthesis. J Bone Joint Surg Am. 1955;37:1074-84.

69. Vermeulen H, De Doncker E, Watillon M. [The Mac Keever patellar prosthesis in femoro-patellar arthrosis]. Acta Orthop Belg. 1973;39:79-90. French.

70. Pickett JC, Stoll DA. Patellaplasty or patellectomy? Clin Orthop Relat Res. 1979;144:103-6.

71. Harrington KD. Long-term results for the McKeever patellar resurfacing prosthesis used as a salvage procedure for severe chondromalacia patellae. Clin Orthop Relat Res. 1992;279:201-13.

72. Aglietti P, Insall JN, Walker PS, Trent P. A new patella prosthesis. Design and application. Clin Orthop Relat Res. 1975;107:175-87.

73. Worrell RV. Prosthetic resurfacing of the patella. Clin Orthop Relat Res. 1979;144:91-7.

74. Worrell RV. Resurfacing of the patella in young patients. Orthop Clin North Am. 1986;17:303-9.

75. Lubinus HH. Patella glide bearing total replacement. Orthopedics. 1979; 2:119-27.

76. Blazina ME, Fox JM, Del Pizzo W, Broukhim B, Ivey FM. Patellofemoral replacement. Clin Orthop Relat Res. 1979;144:98-102.

77. Cartier P, Sanouiller JL, Grelsamer R. Patellofemoral arthroplasty. 2-12-year follow-up study. J Arthroplasty. 1990;5:49-55.

78. Mansat C, Rufo D. Contribution à l'etude des arthroplasties du genou type Marmor. A Propos de 61 cas. Thesis. Toulouse. 1977.

79. Argenson JN, Guillaume JM, Aubaniac JM. Is there a place for patellofemoral arthroplasty? Clin Orthop Relat Res. 1995;321:162-7.

80. Krajca-Radcliffe JB, Coker TP. Patellofemoral arthroplasty. A 2- to 18-year followup study. Clin Orthop Relat Res. 1996;330:143-51.

81. Mertl P, Van FT, Bonhomme P, Vives P. [Femoropatellar osteoarthritis treated by prosthesis. Retrospective study of 50 implants]. Rev Chir Orthop Reparatrice Appar Mot. 1997;83:712-8. French.

82. Mazas FB. Guepar total knee prosthesis. Clin Orthop Relat Res. 1973;94:211-21.

83. Arnbjornsson AH, Ryd L. The use of isolated patellar prostheses in Sweden 1977-1986. Int Orthop. 1998;22:141-4.

84. De Cloedt P, Legaye J, Lokietek W. [Femoro-patellar prosthesis. A retrospective study of 45 consecutive cases with a follow-up of 3-12 years]. Acta Orthop Belg. 1999;65:170-5. French.

85. Kooijman HJ, Driessen AP, van Horn JR. Long-term results of patellofemoral arthroplasty. A report of 56 arthroplasties with 17 years of follow-up. J Bone Joint Surg Br. 2003;85:836-40.

86. Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. N Engl J Med. 1994;331:889-95.

87. Grelsamer RP, McConnell J. The patella: a team approach. Gaithersburg, Md: Aspen; 1998. p 273.

88. Grelsamer RP, Weinstein CH. Applied biomechanics of the patella. Clin Orthop Relat Res. 2001;389:9-14.

89. Minas T, Bryant T. The role of autologous chondrocyte implantation in the patellofemoral joint. Clin Orthop Relat Res. 2005;436:30-9.

90. Clar C, Cummins E, McIntyre L, Thomas S, Lamb J, Bain L, Jobanputra P, Naugh N. Clinical and cost-effectiveness of autologous chondrocyte implantation for cartilage defects in knee joints: systematic review and economic evaluation. Health Technol Assess. 2005;9:iii-iv, ix-x, 1-82.

91. Derrett S, Stokes EA, James M, Bartlett W, Bentley G. Cost and health status analysis after autologous chondrocyte implantation and mosaicplasty: a retrospective comparison. Int J Technol Assess Health Care. 2005;21:359-67.

92. Heineck AP. The modern operative treatment of fractures of the patella. Surg Gynecol Obstet. 1909;9:177.

93. Brooke R. The treatment of fractured patella by excision. A study of morphology and function. Br J Surg. 1937;24:733-47.

94. Hey Groves EW. A note on the extension apparatus of the knee-joint. Br J Surg. 1936;24:747-8.

95. McFarland B. Excision of patella for recurrent dislocation. J Bone Joint Surg Br. 1948;30:158-9.

96. Scott JC. Fractures of the patella. J Bone Joint Surg Br. 1949;31:76-81.

97. Castaing J, Castellani L, Plisson JL, Delplace J. [Total patellectomy. Technics and results]. Rev Chir Orthop Reparatrice Appar Mot. 1969;55: 259-78. French.

98. Compere CL, Hill JA, Lewinnek GE, Thompson RG. A new method of patellectomy for patellofemoral arthritis. J Bone Joint Surg. Am 1979;61:714-8.

99. de la Caffinière JY. Techniques de la patellectomie totale et rééducation. In: Mansat CH, Bonnel F, Jaeger JH, editors. L'appareil extenseur du genou. Paris: Masson; 1985:232-5.

100. Baker CL, Hughston JC. Miyakawa patellectomy. J Bone Joint Surg Am. 1988;70:1489-94.

101. Miyakawa G. Read at the Annual Meeting of the Southern Medical Association; 1956.

102. Lennox IA, Cobb AG, Knowles J, Bentley G. Knee function after patellectomy. A 12- to 48-year follow-up. J Bone Joint Surg Br. 1994;76:485-7.

103. Ficat RP, Ficat C, Gedeon P, Toussaint JB. Spongialization: a new treatment for diseased patellae. Clin Orthop Relat Res. 1979;144:74-83.

104. Marmor L. Unicompartmental knee arthroplasty. Ten- to 13-year follow-up study. Clin Orthop Relat Res. 1988;226:14-20.

105. Mockford BJ, Beverland DE. Secondary resurfacing of the patella in mobile-bearing total knee arthroplasty. J Arthroplasty. 2005;20:898-902.

106. Yercan HS, Ait Si Selmi T, Neyret P. The treatment of patellofemoral osteoarthritis with partial lateral facetectomy. Clin Orthop Relat Res. 2005; 436:14-9.

107. Insall JN, Dorr LD, Scott RD, Scott WN. Rationale of the knee society clinical rating system. Clin Orthop Relat Res. 1989;248:13-4.

108. Nerubay J, Katnelson A. Osteotomy of the patella. Clin Orthop Relat Res. 1986;207:103-7.

109. Vaquero J, Arriaza R. The patella thinning osteotomy. An experimental study of a new technique for reducing patellofemoral pressure. Int Orthop. 1992;16:372-6.

110. Dellon AL, Mont MA, Mullick T, Hungerford DS. Partial denervation for persistent neuroma pain around the knee. Clin Orthop Relat Res. 1996; 329:216-22.