The Anterior Cruciate Ligament–Deficient Knee and Unicompartmental Arthritis

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KEYWORDS

• Anterior cruciate ligament • ACL deficient • Unicompartmental arthritis
• Unicondylar arthroplasty • UKA • Coper • High tibial osteotomy • Pes bursitis

KEY POINTS

- Anterior cruciate ligament (ACL) insufficiency is not a contraindication for unicondylar knee arthroplasty (UKA).
- Fixed-bearing UKA may be successfully performed with long-term follow-up greater than 8 years in appropriately selected patients with ACL-deficient knees without the need for ACL reconstruction.
- Mobile-bearing UKA should be cautiously performed in patients with an ACL-deficient knee unless a previous or concomitant ACL reconstruction is performed.
- Maximize tibial component fixation; use the largest tibial tray possible without any overhang.
- A posterior tibial slope of less than 5° in ACL-deficient knees is associated with improved outcomes after UKA.
- Patients with a UKA without concomitant ACL reconstruction should expect intermittent pes bursitis for 6 months postoperatively; complete resolution of symptoms is expected.
- Fixed-bearing lateral UKA in the ACL-deficient knee is also successful but should not be attempted in the mobile-bearing knee.

INTRODUCTION

Management of medial and lateral compartment knee osteoarthritis (OA) in an anterior cruciate ligament (ACL)-deficient knee has remained a topic of controversy among orthopedic surgeons. Patient expectations and the desire to maintain a high level of pain-free activity complicate the decision making for this select group of patients.

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Treatment options have ranged from high tibial osteotomy (HTO) with and without ACL reconstruction to total knee arthroplasty (TKA).[1] Recent advances in surgical technique and prosthesis design have made unicondylar knee arthroplasty (UKA) a viable treatment option for the ACL-deficient, arthritic knee (**Fig. 1**).

TREATMENT OPTIONS

High Tibial Osteotomy

It has been well established that varus deformity of the knee can lead to progressive ligamentous laxity. The anatomic abnormalities of alignment, motion, joint position, and ligament defects associated with OA have been classified by Noyes as a single, double, or triple varus knee.[2]

The goal of HTO in the varus knee is to shift the mechanical axis of the knee laterally to decrease the load on the diseased, medial compartment. HTO can be performed with concomitant ACL reconstruction or with multiplane correction of varus angulation and tibial slope to decrease anterior tibial translation in the ACL-deficient knee with isolated medial compartment arthritis.[2] An intercondylar notchplasty is recommended

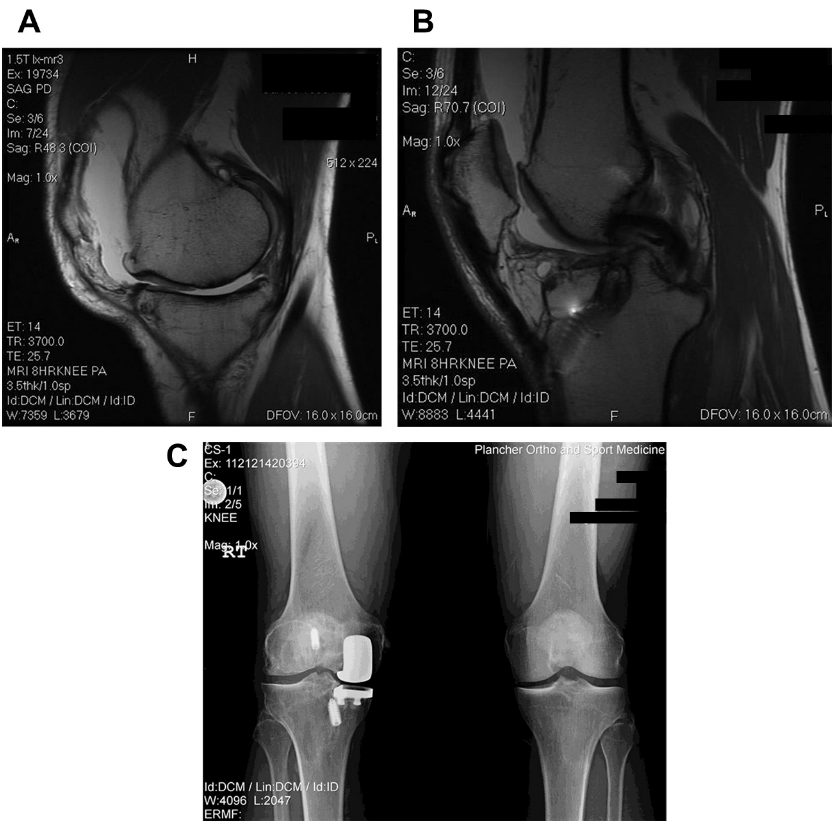

Fig. 1. (*A*) Magnetic resonance (MR) arthrogram sagittal proton density image of medial compartment OA in an ACL-deficient knee. (*B*) MR arthrogram sagittal proton density image of the same patient with a failed previous ACL reconstruction in a medial compartment osteoarthritic knee. (*C*) Postoperative plain radiograph of UKA in ACL-deficient knee in the same patient.

to avoid compromise of the graft and subsequent failure when performing a simultaneous ACL reconstruction and HTO.[3]

One of the drawbacks to HTO is the prolonged, protected weight bearing in the immediate postoperative period. Protection during this healing period negatively affects muscle strength and activation for as long as 1 year postoperatively[4] and potentially magnifies the functional deficits already present as a result of OA.

Although excellent results have been reported by experienced, high-volume surgeons, conflicting evidence is apparent in the literature. Despite survival rates of 98% after 5 years, 92% after 10 years, and 71% after 15 years,[5] high complication rates have also been reported (range 16%–21%).[6,7] In a recent study, 22% of patients undergoing combined ACL reconstruction and closing-wedge osteotomy showed significant progression of OA in the medial compartment 6.5 years postoperatively.[8] Another study reported that 25% of patients had not returned to their previous level of activity 25 months after simultaneous ACL reconstruction and HTO for ACL insufficiency and varus alignment.[9] Therefore, HTO may be a less desirable option for the middle-aged, active individual with an arthritic knee who wants to return to a high level of activity, particularly jumping and pivoting sports, because of poor patient satisfaction and continued pain with activities.[5,10]

Total Knee Arthroplasty

TKA is one of the most successful elective, orthopedic surgeries, resulting in pain relief and excellent survivorship for persons with either unicompartmental or tricompartmental disease.[11,12] Although other procedures for the ACL-deficient, arthritic knee may require some form of ACL reconstruction or osseous realignment, TKA relies entirely on the component design and positioning to provide stability. Although there is the rare component design that may substitute for the ACL, almost all other TKA designs are ACL deficient, either with deficiency present at time of surgery or via sacrifice of the ACL during the surgical procedure. As a result, kinematics of the knee after TKA are not similar to that of the native knee. Evidence suggests that abnormal movement patterns persist after TKA, which may compromise the health of other joints.[13–19]

TKA reliably reduces pain and increases activity level; however, patients report dissatisfaction with their activity level 1 year after surgery.[20] Polyethylene wear is also a concern after TKA. Premature wear has been associated with higher levels of postoperative activity, and therefore, it is recommended that patients avoid activities such as tennis and skiing to avoid stressing the knee and to minimize possible failure.[21] Consequently, patients, regardless of age, desiring an active lifestyle after surgery may be disappointed by the limitations set on them after TKA.[22]

Unicompartmental Knee Arthroplasty

Historically, UKA has not been a viable option for the ACL-deficient, arthritic knee and is still controversial. Concerns of poor survivorship and unpredictable outcomes limit its use in the ACL-deficient knee.

Kozinn and Scott[23] set forth selection criteria for successful UKA in their hallmark study in 1989. They indicated that ACL deficiency in addition to inflammatory arthritis, age younger than 60 years, high activity level, and patellofemoral pain or pain not isolated to the affected compartment are contraindications for UKA. Indications of successful UKA were weight less than 82 kg, minimal pain at rest, an arc of motion greater than 90°, flexion contracture less than 5°, and a passively correctable, angular deformity less than 15°.[23,24] Advances in surgical technique, implant design, and bearing surface technology[25] have contributed to expanded indications for UKA.

Younger, heavier, and more active patients undergoing UKA show excellent results.[26–35]

Early results of UKA in the ACL-deficient knee suggested aseptic loosening of the tibial component and greater eccentric prosthesis wear.[36,37] Goodfellow and colleagues reported a failure rate of 16.2% in the ACL-deficient mobile-bearing UKA,[37] whereas Deschamps and Lapeyre reported a failure rate of 87% in patients with at least 10 mm of preoperative anterior tibial translation on lateral weight-bearing radiograph at 7 years using a fixed-flat-bearing design with no keel.[36] In the mobile-bearing prosthesis, it is believed that ACL deficiency contributes to eccentric loading across the mobile-bearing polyethylene to the tibial base plate, contributing to failure and the need for revision surgery.[38]

More recent evidence suggests both fixed-bearing and mobile-bearing UKA with and without ACL reconstruction are viable options for the ACL-deficient, medial compartment arthritic knee. A revision rate of 1.2% was reported in 575 fixed-bearing UKAs in 415 patients at 9-year follow-up. Although the proportion of ACL-deficient knees was not reported, it was noted that the ACL was frequently absent with associated translatory deformity.[39] Another study of 10 ACL-deficient UKAs at an average of 12 years follow-up (range 10–18 years)[40] reported no patients required revision arthroplasty, 7 of 10 remained asymptomatic at the latest follow-up, 2 of 10 reported mild instability that did not interfere with activities, and 1 of 10 required a secondary ACL reconstruction for instability.

Technical factors such as proper tensioning of the collateral ligaments are key to successful outcomes, particularly in the ACL-deficient knee.[40] Changes in the posterior tibial slope contribute to tensioning of the collateral ligaments; an increase in the posterior tibial slope decreases collateral ligament tension and a decrease in the posterior tibial slope increases collateral ligament tension.[41–43] Fixed-bearing UKA in the ACL-deficient knee requires a smaller posterior tibial slope for a successful outcome. We recommend that the posterior tibial slope should be less than 7°.[41–43] A recent cadaveric model suggested that decreasing the posterior tibial slope of a medial UKA to approximately 4° significantly decreased anterior tibial translation during a Lachman maneuver in the ACL-deficient knee. Anterior tibial translation was not different from that of an ACL-intact knee after altering the posterior tibial slope.[25]

Osteophyte removal is another point of consideration when performing a UKA in the ACL-deficient knee. Osteophytes within the intercondylar notch may function as secondary static stabilizers of the knee.[40] Removal of these osteophytes and the ACL remnant/scar may contribute to postoperative instability. We have found that notch impingement from osteophytes must be dealt with for any successful UKA to attain good motion, but leaving all remnants of the ACL is essential to avoid destabilizing the knee.

The instability felt by a patient is typically not in the anteroposterior (AP) plane but rather in the medial-lateral plane. We believe that this instability is a result of medial collateral ligament shortening, which occurs preoperatively with the normal progression of OA. The direction of instability, if any, can be distinguished on careful history to help ensure a successful outcome in the ACL-deficient knee requiring a UKA. UKA remains an option in patients reporting medial-lateral instability during functional activities, whereas alternative treatment options should be explored in patients reporting AP instability.

Combined UKA and ACL Reconstruction

Another option for the ACL-deficient, arthritic knee is to reconstruct the ACL either before or at the time of the UKA. Early to midterm results are promising for both mobile-bearing and fixed-bearing prostheses.[44–48] Survivorship has been reported to be 93% at an average 5-year follow-up in 52 staged or simultaneous UKAs with ACL reconstruction[48] and 100% in 27 patients undergoing combined ACL-UKA reconstruction with evidence of improved knee stability.[46] Although these results are encouraging, more long-term outcomes studies are needed.

Concerns with a combined procedure include postoperative stiffness, improperly positioned ACL graft tunnels secondary to the prosthesis, graft impingement, undersizing of the tibial base plate to avoid graft impingement, the potential for a stress raiser or delayed proximal tibia fracture, and the risk of aseptic loosening of the tibial base plate, particularly in a mobile-bearing design if ACL reconstruction fails. As a result, staged reconstruction has been favored by our group. We have recently performed subchondroplasty for bony edema (insufficiency fractures) to avoid stress raisers and delayed fractures as well as to minimize the risk of aseptic loosening of the tibial component to ensure an excellent outcome.[49,50]

SELECTION CRITERIA

Patient Selection for UKA in the ACL-Deficient Patient

Patient selection is crucial for successful outcomes. Clinical decision making is challenging and should not be taken lightly by surgeon or patient alike.[51] Conservative treatment regimens should be exhausted before any surgical intervention. Although data may be lacking for the arthritic, ACL-deficient knee in the young, active individual, the surgeon can use the abundance of data in the younger, athletic ACL-deficient knee literature to guide operative treatment.[52]

The terminology of coper and noncoper emerged in the ACL literature to define the population of patients who have the ability to dynamically stabilize or cope with their knee disorder (eg, no instability events despite lacking a functional ACL).[53] In addition to the static, ligamentous stabilizers of the knee, dynamic stabilizers (eg, muscular contractions of the quadriceps, hamstrings and gastrocnemius muscles[54–56] and neuromuscular and proprioceptive physiologic responses[57–60]) contribute to knee stability during functional tasks. Studies have shown that high-level, ACL-deficient athletes without a reconstructed ACL perform similar to their peers who underwent ACL reconstruction at 10 years.[61] Likewise, many professional mogul skiers who have had an ACL reconstruction and overtime no longer have a functional ACL perform as well as their colleagues without a brace, performing to a level of excellence not fully understood.

Identification of ACL-Deficient Osteoarthritic Copers

A thorough history should always be conducted to identify knee instability. Specific questions without leading the patient should be asked by the surgeon. This process may take time but is worth the effort to manage expectations, leading to excellent long-term outcomes, in our opinion. The 1-finger test (ie, using 1 finger to point to the uncomfortable area) is used to determine the location of discomfort followed by a discussion about the noted instability (**Fig. 2**). It is important to decipher whether the instability is felt side to side or front to back. Almost all patients with an attritional tear of the ACL or chronic tear describe a side-to-side feeling of giving out. The description we use is “a knee falling into a pothole on the street.” Most patients have a tight capsule because of the slow progression of their arthritis. Capsular contracture minimizes AP instability or giving way and can serve as a good indicator of patients who can have a successful UKA without an ACL reconstruction and return to a high level of activity. Reports of AP instability/subluxation events serve as a contraindication for UKA without reconstructing the ACL.

Fig. 2. The 1-finger test. On physical examination, the patient must point to the area of pain (*arrow*) with 1 finger to identify the area of discomfort.

Screening tools have been developed to identify copers from noncopers in the young, ACL-deficient, nonarthritic population.[62,63] A complete physical examination, including quadriceps strength testing, perturbation tolerance, timed, 6-meter single-leg hop test in the young athlete, and other plyometric testing, have been suggested as indicators of a person's ability to dynamically stabilize their knee when they have a compromised ACL.[51–57,61] Plyometric testing can be challenging in the older, arthritic population, because of pain and impact loading of the involved knee. Adaptations in the screening process can improve patient tolerance to testing and make the screening process more applicable to this patient subset with symptomatic OA. Because altered knee and gait biomechanics are well documented in the ACL-deficient patient population,[64,65] we suggest substituting single-leg hop testing with ambulation up and down stairs and a single limb step-down test to assess for instability with functional activities. Trampoline walking can also be used to ensure no frank instability. A common finding in this population is not a complaint of pain ascending stairs in the varus knee (pain ascending stairs is more commonly associated with the valgus knee) but rather more discomfort over the medial compartment descending stairs. Quadriceps and hamstring strength testing on an isokinetic dynamometer can also be performed; we recommend strength to be a minimum of 70% of the contralateral side.[66] For rare patients who would like to return to high-level, competitive singles tennis or soccer, we perform perturbation training and require no feeling of instability on a roller board or tilt board. We recommend a fixed-bearing UKA for this group of patients, whom we refer to as copers.

Additional criteria for considering a UKA for the ACL-deficient knee without concomitant ACL reconstruction include:

- Varus/valgus stability at 0° and 30° flexion with no more than 8-mm excursion and a firm end point
- Flexible varus deformity less than 15°, correctable to neutral with or without stress radiographs
- No tibial pseudosubluxation on an AP film of the knee (**Fig. 3**)
- Flexion range of motion of at least 105°
- A correctable flexion contracture of up to 5° is an acceptable finding with limited anterior subluxation of the tibia on the lateral extension radiographs

Noncopers are classified as having the following symptoms, no different from the copers as described earlier, with some exceptions. This group of patients do experience a giving way in the AP direction, much like a classic ACL-deficient patient describes. Their KT-1000 knee laxity testing device often shows greater than 10-mm side-to-side difference on manual maximum exertion. There are often episodes of giving out on a tilt board or any uneven ground testing. We recommend a staged procedure for these ACL-deficient, arthritic knees with an ACL reconstruction (bone-patellar tendon-bone allograft; graft donors always <40 years of age, because of the change in the collagen content) and a fixed-bearing prosthesis.

Contraindications to UKA in the ACL-deficient, arthritic knee are still those accepted by many when the patient has a fixed varus deformity (eg, not flexible on examination, not correctable to neutral on stress view radiograph). If the fixed varus deformity is greater than 8°, we do not offer an ACL reconstruction. If a UKA is performed in this subset of patients, the patient must understand they will continue to have a varus thrust yet no discomfort. If there is persistent anterior subluxation of the tibia, (>5 mm on a lateral weight-bearing radiograph), ACL reconstruction must be performed before a UKA. Patients with a fixed flexion contracture greater than 12° or a previous HTO, lateral compartment degenerative changes (Ahlback Stage 3 or higher)[67] and/or subluxation, and/or tricompartmental arthritis are all contraindicated for a UKA with an ACL reconstruction. All patients who undergo UKA with an ACL-deficient knee should

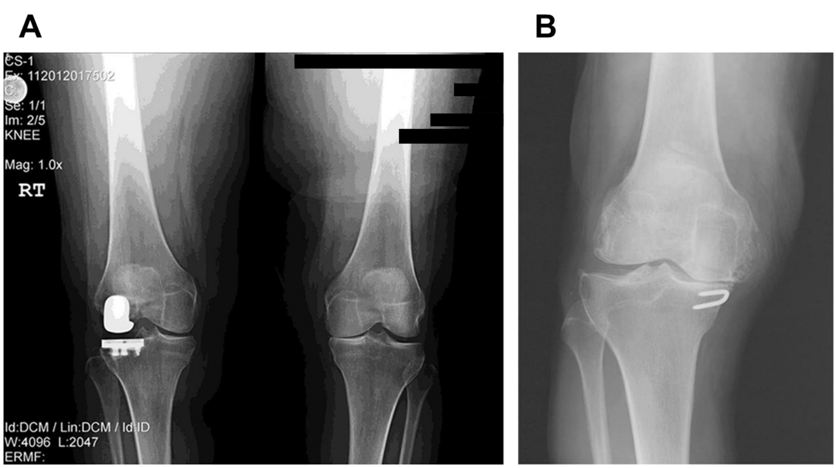

Fig. 3. (*A*) Preoperative radiograph (AP view) in an osteoarthritic ACL-deficient left knee. No evidence of tibial pseudosubluxation. (*B*) Evidence of pseudosubluxation.

expect pes bursitis, which typically resolves within 6 months. Pes bursitis in this population is treated conservatively and at times may require a steroid injection.

PREOPERATIVE PLANNING

It is hoped that setting preoperative guidelines has been reinforced in this article for successful outcomes. Education by the surgeon and health care provider (eg, nurse practitioner, physician assistant) should be provided pertaining to the risks, benefits, and alternative procedures so that patient and surgeon expectations are consistent. The patient's postoperative expectations are integral to the decision-making process in order to maximize long-term, postoperative outcomes with excellent patient satisfaction.[68]

SURGICAL PROCEDURE

The surgical approach we use, instrumentation use, and technique are explained in detail in the article on "Unicondylar Knee Arthroplasty: Intramedullary Technique" by Dunn and colleagues elsewhere in this issue. We use a fixed-bearing intramedullary technique with the distal femur cut first to be able to treat patients with flexion contractures preoperatively.

When a UKA is performed in the ACL-deficient knee, the intercondylar notch is carefully debrided of osteophytes in an effort to maintain stability (**Fig. 4**).[69,70] The fat pad is excised for visualization and to ensure that any restraint is removed for excellent patellar mobilization. The proximal tibial cut is set for 4-mm depth of resection, with a starting posterior tibial slope of 4°. If a solid anterior end point is not felt, the posterior tibial slope is then recut at 0° (**Fig. 5**). After insertion of trials, the knee is tensioned appropriately with a 2-mm tension gauge for a 9-mm or 10-mm polyethylene insert. The anterior drawer test is performed with the knee flexed to 90° and neutral rotation and the Lachman maneuver is performed in 30° of flexion. With proper patient

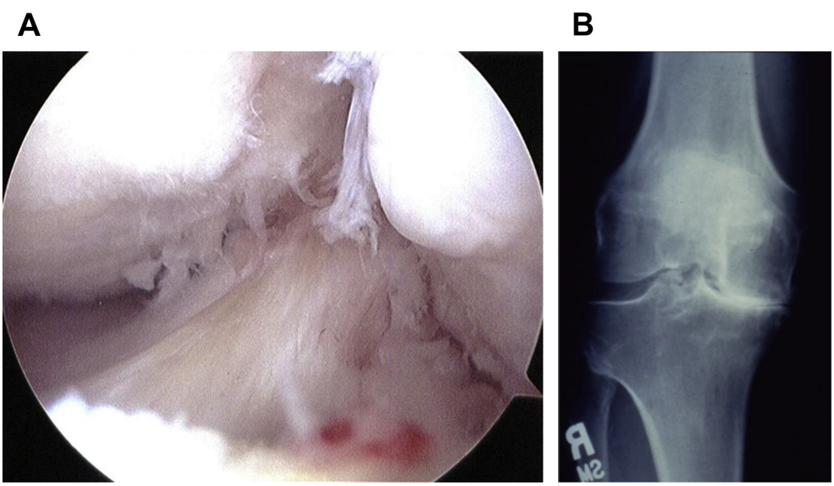

Fig. 4. (*A*) Arthroscopic image of notch impingement in an ACL-competent knee. Osteophytes are routinely removed to avoid notch impingement after placing a UKA. (*B*) AP plain radiograph in an ACL-deficient medial compartment osteoarthritic right knee with classic impingement. In ACL-deficient knees, the intercondylar notch is carefully debrided of osteophytes to maintain stability in the knee.

Fig. 5. Proximal tibial cut. The proximal tibial cut is initially set for 4-mm depth of resection and a starting posterior tibial slope of 4°.

selection, there is rarely a need to recut the tibia. The rest of the procedure is similar to an ACL-competent knee.

POSTOPERATIVE MANAGEMENT

Postoperative management is similar to reconstruction UKA. Although literature is lacking for the rehabilitation of patients with ACL-deficient UKA, intuitively, the incorporation of perturbation training, which has shown to be beneficial in rehabilitation protocols after ACL reconstruction, may be of great value and is certainly deserving of more research.[71] Our ACL rehabilitation is conservative and does not allow for any return to pivoting sports before 6 months. Patients undergoing UKA ACL-deficient or ACL-competent refrain from these activities for the same period.

OUTCOMES

Our review of the last 10 patients with ACL-deficient, arthritic knee performed by KDP has been promising. At the latest follow-up (mean 2.9 $\pm$ 3.0 years, range 1–8 years), patients with ACL-deficient UKA had similar outcomes to age, BMI, and gender-matched patients with UKA and competent ACL. Our patients with ACL-deficient knee and UKA have a Lysholm score of 92.4 $\pm$ 8.6, a Tegner score of 4.5 $\pm$ 2.0, a Hospital for Special Surgery score of 93.7 $\pm$ 7.6, a patient satisfaction score of 9.6 $\pm$ 0.82 (maximum score 10), knee flexion range of motion of 133° $\pm$ 11°, and knee extension range of motion 0°. Patients have returned to their previous recreational activities, including tennis and skiing.

SUMMARY

Management of the adult younger than 55 years and the physiologically mature adult with medial compartments arthritis and an ACL-deficient knee having failed conservative and simpler interventions remains a topic of debate and requires careful thought to manage. We have had success using our selection process. Our most common complication in the non-ACL reconstructed UKA is pes anserine bursitis. The bursitis typically emerges within the first 6 months postoperatively, typically at around 6 weeks, and is most likely related to increased pull from the hamstrings as a dynamic stabilizer in the now more mobile ACL-deficient knee. We have used classic, steroid injections for treatment of this event, with complete resolution in all patients by 6 months after UKA. Proper patient selection and education are the keys to success with this procedure. New surgical techniques have arisen that may prove to be successful over time; however, long-term follow-up (>15 years) is still required.

REFERENCES

1. Williams RJ III, Wickiewicz TL, Warren RF. Management of unicompartmental arthritis in the anterior cruciate ligament-deficient knee. Am J Sports Med 2000;28(5):749–60.
2. Noyes FR, Barber SD, Simon R. High tibial osteotomy and ligament reconstruction in varus angulated, anterior cruciate ligament-deficient knees. A two- to seven-year follow-up study. Am J Sports Med 1993;21(1):2–12.
3. Akamatsu Y, Mitsugi N, Taki N, et al. Simultaneous anterior cruciate ligament reconstruction and opening wedge high tibial osteotomy: Report of four cases. Knee 2010;17(2):114–8.
4. Machner A, Pap G, Krohn A, et al. Quadriceps muscle function after high tibial osteotomy for osteoarthritis of the knee. Clin Orthop Relat Res 2002;(399): 177–83.
5. Schallberger A, Jacobi M, Wahl P, et al. High tibial valgus osteotomy in unicompartmental medial osteoarthritis of the knee: A retrospective follow-up study over 13-21 years. Knee Surg Sports Traumatol Arthrosc 2011;19(1):122–7.
6. Brouwer RW, Bierma-Zeinstra SM, van Raaij TM, et al. Osteotomy for medial compartment arthritis of the knee using a closing wedge or an opening wedge controlled by a Puddu plate. A one-year randomised, controlled study. J Bone Joint Surg Br 2006;88(11):1454–9.
7. Sprenger TR, Doerzbacher JF. Tibial osteotomy for the treatment of varus gonarthrosis. Survival and failure analysis to twenty-two years. J Bone Joint Surg Am 2003;85(3):469–74.
8. Zaffagnini S, Bonanzinga T, Grassi A, et al. Combined ACL reconstruction and closing-wedge HTO for varus angulated ACL-deficient knees. Knee Surg Sports Traumatol Arthrosc 2013;21(4):934–41.
9. Graveleau N, DaSilva J, Litchfield R, et al. Clinical outcome after combined anterior cruciate ligament reconstruction and medial opening wedge high tibial osteotomy. J Bone Joint Surg Br 2008;90(Suppl I):109.
10. Bonnin MP, Salreta JF, Chambat P, et al. What can we really do following TKA, UKA and HTO? Arthroscopy 2012;28(9):e339–40.
11. Meding JB, Meding LK, Ritter MA, et al. Pain relief and functional improvement remain 20 years after knee arthroplasty. Clin Orthop Relat Res 2012;470(1):144–9.
12. Font-Rodriguez DE, Scuderi GR, Insall JN. Survivorship of cemented total knee arthroplasty. Clin Orthop Relat Res 1997;(345):79–86.
13. Alnahdi AH, Zeni JA, Snyder-Mackler L. Gait after unilateral total knee arthroplasty: frontal plane analysis. J Orthop Res 2011;29(5):647–52.
14. Yoshida Y, Mizner RL, Ramsey DK, et al. Examining outcomes from total knee arthroplasty and the relationship between quadriceps strength and knee function over time. Clin Biomech (Bristol, Avon) 2008;23(3):320–8.
15. Dennis DA, Komistek RD, Kim RH, et al. Gap balancing versus measured resection technique for total knee arthroplasty. Clin Orthop Relat Res 2010;468(1): 102–7.
16. Dennis DA, Komistek RD, Hoff WA, et al. In vivo knee kinematics derived using an inverse perspective technique. Clin Orthop Relat Res 1996;(331):107–17.

17. Stiehl JB, Dennis DA, Komistek RD, et al. In vivo determination of condylar lift-off and screw-home in a mobile-bearing total knee arthroplasty. J Arthroplasty 1999;14(3):293–9.
18. Stiehl JB, Komistek RD, Dennis DA, et al. Fluoroscopic analysis of kinematics after posterior-cruciate-retaining knee arthroplasty. J Bone Joint Surg Br 1995; 77(6):884–9.
19. Brugioni DJ, Andriacchi TP, Galante JO. A functional and radiographic analysis of the total condylar knee arthroplasty. J Arthroplasty 1990;5(2): 173–80.
20. Jones DL, Bhanegaonkar AJ, Billings AA, et al. Differences between actual and expected leisure activities after total knee arthroplasty for osteoarthritis. J Arthroplasty 2012;27(7):1289–96.
21. Lavernia CJ, Sierra RJ, Hungerford DS, et al. Activity level and wear in total knee arthroplasty: A study of autopsy retrieved specimens. J Arthroplasty 2001;16(4): 446–53.
22. Healy WL, Iorio R, Lemos MJ. Athletic activity after total knee arthroplasty. Clin Orthop Relat Res 2000;(380):65–71.
23. Kozinn SC, Scott R. Unicondylar knee arthroplasty. J Bone Joint Surg Am 1989; 71(1):145–50.
24. Borus T, Thornhill T. Unicompartmental knee arthroplasty. J Am Acad Orthop Surg 2008;16(1):9–18.
25. Oral E, Neils AL, Rowell SL, et al. Increasing irradiation temperature maximizes vitamin E grafting and wear resistance of ultrahigh molecular weight polyethylene. J Biomed Mater Res B Appl Biomater 2013;101(3):436–40.
26. Repicci JA, Hartman JF. Minimally invasive unicondylar knee arthroplasty for the treatment of unicompartmental osteoarthritis: An outpatient arthritic bypass procedure. Orthop Clin North Am 2004;35(2):201–16.
27. Price AJ, Waite JC, Svard U. Long-term clinical results of the medial Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res 2005;(435): 171–80.
28. Naudie D, Guerin J, Parker DA, et al. Medial unicompartmental knee arthroplasty with the Miller-Galante prosthesis. J Bone Joint Surg Am 2004;86(9): 1931–5.
29. Keblish PA, Briard JL. Mobile-bearing unicompartmental knee arthroplasty: A 2-center study with an 11-year (mean) follow-up. J Arthroplasty 2004;19(7 Suppl 2):87–94.
30. Berger RA, Meneghini RM, Jacobs JJ, et al. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am 2005; 87(5):999–1006.
31. Argenson JN, Chevrol-Benkeddache Y, Aubaniac JM. Modern unicompartmental knee arthroplasty with cement: A three to ten-year follow-up study. J Bone Joint Surg Am 2002;84(12):2235–9.
32. Swienckowski JJ, Pennington DW. Unicompartmental knee arthroplasty in patients sixty years of age or younger. J Bone Joint Surg Am 2004;86(Suppl 1 (Pt 2)):131–42.
33. Price AJ, Dodd CA, Svard UG, et al. Oxford medial unicompartmental knee arthroplasty in patients younger and older than 60 years of age. J Bone Joint Surg Br 2005;87(11):1488–92.
34. Pennington DW, Swienckowski JJ, Lutes WB, et al. Unicompartmental knee arthroplasty in patients sixty years of age or younger. J Bone Joint Surg Am 2003;85(10):1968–73.

35. Tabor OB Jr, Tabor OB, Bernard M, et al. Unicompartmental knee arthroplasty: long-term success in middle-age and obese patients. J Surg Orthop Adv 2005; 14(2):59–63.
36. Deschamps G, Lapeyre B. Rupture of the anterior cruciate ligament: A frequently unrecognized cause of failure of unicompartmental knee prostheses. Apropos of a series of 79 Lotus prostheses with a follow-up of more than 5 years. Rev Chir Orthop Reparatrice Appar Mot 1987;73(7):544–51 [in French].
37. Goodfellow JW, Kershaw CJ, Benson MK, et al. The Oxford knee for unicompartmental osteoarthritis. The first 103 cases. J Bone Joint Surg Br 1988;70(5): 692–701.
38. Goodfellow J, O'Connor J. The anterior cruciate ligament in knee arthroplasty. A risk-factor with unconstrained meniscal prostheses. Clin Orthop Relat Res 1992;(276):245–52.
39. Christensen NO. Unicompartmental prosthesis for gonarthrosis. A nine-year series of 575 knees from a Swedish hospital. Clin Orthop Relat Res 1991;(273): 165–9.
40. Cartier P, Sanouiller JL, Grelsamer RP. Unicompartmental knee arthroplasty surgery. 10-year minimum follow-up period. J Arthroplasty 1996;11(7):782–8.
41. Shao Q, MacLeod TD, Manal K, et al. Estimation of ligament loading and anterior tibial translation in healthy and ACL-deficient knees during gait and the influence of increasing tibial slope using EMG-driven approach. Ann Biomed Eng 2011;39(1):110–21.
42. Voos JE, Suero EM, Citak M, et al. Effect of tibial slope on the stability of the anterior cruciate ligament-deficient knee. Knee Surg Sports Traumatol Arthrosc 2012;20(8):1626–31.
43. Hernigou P, Deschamps G. Posterior slope of the tibial implant and the outcome of unicompartmental knee arthroplasty. J Bone Joint Surg Am 2004;86(3): 506–11.
44. Krishnan SR, Randle R. ACL reconstruction with unicondylar replacement in knee with functional instability and osteoarthritis. J Orthop Surg Res 2009;4:43.
45. Pandit H, Van Duren BH, Gallagher JA, et al. Combined anterior cruciate reconstruction and Oxford unicompartmental knee arthroplasty: In vivo kinematics. Knee 2008;15(2):101–6.
46. Tinius M, Hepp P, Becker R. Combined unicompartmental knee arthroplasty and anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2012;20(1):81–7.
47. Pandit H, Beard DJ, Jenkins C, et al. Combined anterior cruciate reconstruction and Oxford unicompartmental knee arthroplasty. J Bone Joint Surg Br 2006; 88(7):887–92.
48. Weston-Simons JS, Pandit H, Jenkins C, et al. Outcome of combined unicompartmental knee replacement and combined or sequential anterior cruciate ligament reconstruction: A study of 52 cases with mean follow-up of five years. J Bone Joint Surg Br 2012;94(9):1216–20.
49. Sharkey PF, Cohen SB, Leinberry CF, et al. Subchondral bone marrow lesions associated with knee osteoarthritis. Am J Orthop 2012;41(9):413–7.
50. Roemer FW, Guermazi A, Javaid MK, et al. Change in MRI-detected subchondral bone marrow lesions is associated with cartilage loss: The MOST Study. A longitudinal multicentre study of knee osteoarthritis. Ann Rheum Dis 2009; 68(9):1461–5.
51. Sutton PM, Holloway ES. The young osteoarthritic knee: Dilemmas in management. BMC Med 2013;11:14.

52. Keyes GW, Carr AJ, Miller RK, et al. The radiographic classification of medial gonarthrosis. Correlation with operation methods in 200 knees. Acta Orthop Scand 1992;63(5):497–501.
53. Daniel DM, Stone ML, Dobson BE, et al. Fate of the ACL-injured patient. A prospective outcome study. Am J Sports Med 1994;22(5):632–44.
54. Andriacchi TP. Dynamics of pathological motion: Applied to the anterior cruciate deficient knee. J Biomech 1990;23(Suppl 1):99–105.
55. Limbird TJ, Shiavi R, Frazer M, et al. EMG profiles of knee joint musculature during walking: Changes induced by anterior cruciate ligament deficiency. J Orthop Res 1988;6(5):630–8.
56. Shiavi R, Zhang LQ, Limbird T, et al. Pattern analysis of electromyographic linear envelopes exhibited by subjects with uninjured and injured knees during free and fast speed walking. J Orthop Res 1992;10(2):226–36.
57. Wilk KE. Rehabilitation of isolated and combined posterior cruciate ligament injuries. Clin Sports Med 1994;13(3):649–77.
58. Johansson H, Sjolander P, Sojka P. Receptors in the knee joint ligaments and their role in the biomechanics of the joint. Crit Rev Biomed Eng 1991;18(5):341–68.
59. Johansson H. Role of knee ligaments in proprioception and regulation of muscle stiffness. J Electromyogr Kinesiol 1991;1(3):158–79.
60. Lephart SM, Pincivero DM, Giraldo JL, et al. The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 1997;25(1):130–7.
61. Meuffels DE, Favejee MM, Vissers MM, et al. Ten year follow-up study comparing conservative versus operative treatment of anterior cruciate ligament ruptures. A matched-pair analysis of high level athletes. Br J Sports Med 2009;43(5):347–51.
62. Fitzgerald GK, Axe MJ, Snyder-Mackler L. A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. Knee Surg Sports Traumatol Arthrosc 2000;8(2):76–82.
63. Moksnes H, Snyder-Mackler L, Risberg MA. Individuals with an anterior cruciate ligament-deficient knee classified as noncopers may be candidates for nonsurgical rehabilitation. J Orthop Sports Phys Ther 2008;38(10):586–95.
64. Berchuck M, Andriacchi TP, Bach BR, et al. Gait adaptations by patients who have a deficient anterior cruciate ligament. J Bone Joint Surg Am 1990;72(6):871–7.
65. Andriacchi TP, Birac D. Functional testing in the anterior cruciate ligament-deficient knee. Clin Orthop Relat Res 1993;(288):40–7.
66. Taylor NA, Sanders RH, Howick EI, et al. Static and dynamic assessment of the Biodex dynamometer. Eur J Appl Physiol Occup Physiol 1991;62(3):180–8.
67. Ahlback S. Osteoarthrosis of the knee. A radiographic investigation. Acta Radiol Diagn (Stockh) 1968;(Suppl 277):7–72.
68. Greene KA, Harwin SF. Maximizing patient satisfaction and functional results after total knee arthroplasty. J Knee Surg 2011;24(1):19–24.
69. Hasegawa A, Otsuki S, Pauli C, et al. Anterior cruciate ligament changes in the human knee joint in aging and osteoarthritis. Arthritis Rheum 2012;64(3):696–704.
70. Wada M, Tatsuo H, Baba H, et al. Femoral intercondylar notch measurements in osteoarthritic knees. Rheumatology 1999;38(6):554–8.
71. Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. Phys Ther 2000;80(2):128–40.