SciMedCentral

Annals of Sports Medicine and Research

Case Report

Opening Wedge High Tibial Osteotomy, Microfracture, and Bone Marrow Aspirate Concentrate for Treatment of Varus Deformity and Osteoarthritis of the Knee

Evan W. James*, Keith T. Corpus, Austin T. Fragomen, and S. Robert Rozbruch

Limb Lengthening and Complex Reconstruction Service, Hospital for Special Surgery, USA

***Corresponding author**

Evan W. James, Hospital for Special Surgery, 535 East 70th Street, New York, New York 10021, USA, Tel: +1-212-606-1000; Email: jamese@hss.edu

Submitted: 04 April 2017

Accepted: 03 May 2017

Published: 05 May 2017

ISSN: 2379-0571

Keywords

- High tibial osteotomy
- Microfracture
- Bone marrow aspirate concentrate
- Limb lengthening and deformities
- Tibia vara

Abstract

Osteoarthritis in the setting of varus deformity can be difficult to treat in young and middle aged patients. Treatment options typically include arthroplasty versus joint preservation techniques. In young and middle aged patients, unicompartmental or total knee arthroplasty is often considered a less desirable treatment option due to the increased likelihood of requiring revision arthroplasty later in life. Joint preserving techniques, which combine a high tibial osteotomy to restore a neutral or even overcorrected mechanical axis with a cartilage resurfacing or transplantation procedure, are typically preferred. Recently, some researchers have advocated for biologic augmentation of cartilage resurfacing techniques using autologous stem cells. The purpose of this report is to present two patients with a varus mechanical axis deformity and extensive grade IV medial compartment osteoarthritis treated with a medial opening wedge high tibial osteotomy (HTO) and microfracture augmented with bone marrow aspirate concentrate (BMAC). Results of these two cases demonstrate restoration of a neutral mechanical axis, filling of the osteochondral defect observed on second look arthroscopy, and improvement in subjective outcome scores. While short-term results appear encouraging in this and other reports, long-term follow-up is needed to evaluate the efficacy of joint preserving techniques in patients with large osteochondral defects for delaying or preventing conversion to arthroplasty.

INTRODUCTION

Young and middle aged patients with pain and disability due to varus deformity and medial compartment osteoarthritis (OA) can be difficult to treat. If non-operative measures fail to relieve symptoms, patients are typically offered one of three surgical treatment options: unicompartmental knee arthroplasty (UKA), total knee arthroplasty (TKA), or a joint preserving surgery such as high tibial osteotomy (HTO) with or without cartilage resurfacing or transplantation. While the role of HTO for joint preservation has been well described for over 50 years [1-5], there has been a trend within the past decade toward increased utilization of arthroplasty compared to joint preserving techniques. Reasons for this transition are unclear. A study by Nwackukwu et al., queried a large US private payer database from 2007 to 2011 [6] to compare utilization rates of unicompartmental knee arthroplasty to HTO. Results showed a compound annual utilization grown rate of +4.7% in unicompartmental knee arthroplasties while utilization of HTO decreased -3.9%. The authors speculated that the decreasing utilization rate of HTO may be attributable to lack of clear indications for HTO and lack of familiarity with the procedure.

When HTO is performed, cartilage repair or transplantation may be performed concurrently. Cartilage-addressing surgeries include debridement and lavage, microfracture, osteochondral autograft, osteochondral allograft, or autologous chondrocyte implantation. Over the past several years, biologic augmentation of cartilage repair techniques using bone marrow aspirate concentrate (BMAC) has gained favorability [7-9]. Augmentation is performed with the goal of increasing fill rates, improving tissue quality, and extending repair longevity [10,11]. This is especially important for large-sized defects greater than one square centimetre. Taken together, evidence suggests that joint preserving surgery results in a high rate of return to work and sport [12], improved pain and functional level [8,13-17], greater cost effectiveness [18], and successful delay or prevention of conversion to arthroplasty in greater than 90% of patients at mid-

term follow-up [19-21]. The purpose of this report is to present two patients with a varus mechanical axis deformity and large symptomatic grade IV chondral lesions treated with a medial opening wedge HTO and microfracture augmented with BMAC and to report clinical, radiographic, and arthroscopic outcomes at two-year follow-up.

CASE PRESENTATION

Patient 1: Characteristics

The patient is a 45 year-old male who was referred to our service for evaluation of a six-month history of left knee pain. He noted swelling and pain in the posteromedial aspect of his knee that was worse with walking and going up or down stairs. He tried physical therapy, anti-inflammatory medications, and multiple corticosteroid injections without relief of symptoms. There was no history of trauma to the left knee. On physical exam, the patient had a body mass index (BMI) of 29.0. On standing, a varus mechanical axis deformity was evident in the left leg. Gait was antalgic due to left knee pain. There was no evidence of anterior, posterior, varus, or valgus knee instability. Range of motion was from 0 to 110 degrees in the left knee and 0 to 130 degrees in the right knee. There was a large effusion on the left. Anteroposterior radiographs of the left knee showed joint space narrowing in the medial compartment (Figure 1A). Standing full length alignment radiographs showed a varus deformity in the left lower extremity with a 31mm medial mechanical axis deviation (MAD). Joint line orientation angles demonstrated the lateral distal femoral angle (LDFA) to measure 88 degrees, while the medial proximal tibial angle (MPTA) measured 84 degrees, indicating the varus deformity was secondary to tibia vara (Figures 2A, 2B).

Treatment options including non-operative management, unicompartmental knee arthroplasty, and joint preserving surgery were discussed with the patient. After considering all options, the patient elected to proceed with a joint preserving approach which included medial opening wedge HTO and microfracture augmented with BMAC to promote enhanced cartilage repair.

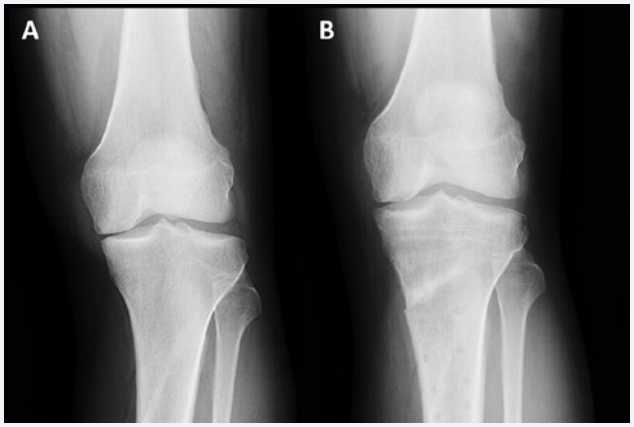

Figure 1 Preoperative anteroposterior left knee radiograph (A) of Patient 1 demonstrating joint space narrowing in the medial compartment; (B) post-operative anteroposterior radiograph demonstrating improved medial compartment joint space compared to pre-operative imaging.

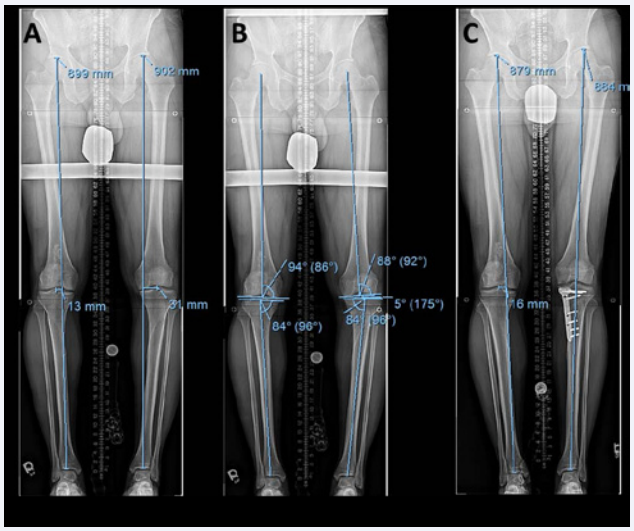

Figure 2 Standing full length alignment radiographs of Patient 1 showing (A) a varus deformity in the left lower extremity with a 31mm medial mechanical axis deviation (MAD), and (B) joint line congruency angles at the lateral distal femoral angle (LDFA) measuring 88 degrees and the medial proximal tibial angle (MPTA) measuring 84 degrees, indicating varus deformity secondary to tibia vara. A post-operative standing full length alignment radiograph (C) showed restoration of a neutral mechanical axis in the left lower extremity.

Patient 1: Surgical technique

The patient was positioned supine and regional anesthesia administered. The operative lower extremity and ipsilateral iliac crest were prepped and draped in a sterile fashion. A trocar was advanced between the inner and outer tables of the ilium 4 cm posterior to the anterior superior iliac spine and 60 mL of bone marrow was aspirated. The bone marrow aspirate was centrifuged using the Harvest system (Harvest Technologies, Lakewood, CO) to obtain a supply of autologous BMAC.

Next, left knee arthroscopy was performed through conventional medial and lateral parapatellar arthroscopic portals. Arthroscopic examination at the time of the index surgery showed a normal patella and trochlear groove. There were no cartilage defects in the lateral compartment and the lateral meniscus was intact. The medial compartment had full-thickness loss of cartilage on the medial femoral condyle measuring 20 mm by 30 mm (Figure 3A). The tibia had full-thickness cartilage loss in the posteromedial zone measuring 10 mm by 12 mm. The medial meniscus was intact. Using an arthroscopic shaver, loose cartilage was debrided from the femoral lesion back to a stable rim. Microfracture was performed on the medial femoral condyle using a 1.8 mm wire to create multiple drill holes spaced approximately 3 to 4 mm apart as is our preferred technique for large sized lesions. Angled arthroscopic picks were used to perform microfracture of the tibial lesion since the angle of approach precluded use of a wire (Figure 3B). An arthroscopic burr was used to perform an abrasion arthroplasty to remove the overlying hard subchondral bone. The arthroscopic instruments were then removed.

An Esmarch bandage was used to exsanguinate the limb and a tourniquet was inflated to 250 mmHg. A 10 cm anteromedial

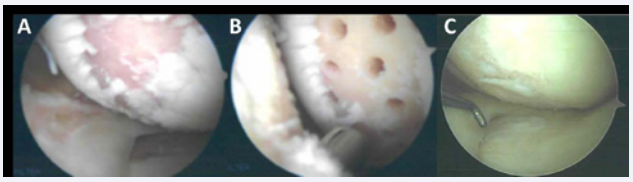

Figure 3 Arthroscopic images of Patient 1 depicting (A) a large grade IV cartilage defect measuring 20 mm by 30 mm on the right medial femoral condyle, (B) microfracture of the lesion, and (C) second look arthroscopy showed fill of the large full thickness defect at follow-up.

skin incision was made and dissection carried down to the proximal medial tibia. At the most proximal extent of the incision, an arthrotomy was performed to inspect the femoral chondral lesion. The osteotomy location and orientation was planned with a wire placed in the medial cortex of the proximal tibia and directed upward in an oblique fashion toward the proximal tibia-fibula joint and proximal to the tibial tubercle. Subperiosteal dissection was performed at the osteotomy site. The patellar tendon was protected by retracting it anteriorly.

A microsagital saw was used to perform the osteotomy using the wire as a guide. The anterior third of the osteotomy was also angled proximally to avoid the tibial tubercle. The lateral cortex was left intact. The osteotomy was then wedged open to the desired distance based on preoperative planning to correct the mechanical axis to a point through the lateral tibial spine. A spacer representing the desired correction was placed in the osteotomy site. The axis was checked intraoperatively using an alignment rod from the center of the hip to the center of the ankle. A medial high tibial osteotomy plate was applied and stabilized using locking screws. The proximal segment screws were unicortical while the distal segment screws were bicortical. The open wedge was irrigated. The osteotomy site was filled with freeze-dried allograft bone chips and demineralized bone matrix putty. BMAC was added to the bone graft. A drain was placed and layered closure of the medial incision performed. Bone marrow aspirate concentrate with calcium chloride and thrombin was then injected into the joint via the medial parapatellar portal over the microfracture site on the medial femoral condyle. Dry sterile dressings were applied and the tourniquet let down. The patient was allowed toe touch weight bearing with a 30 pound limit for the first 6 weeks and advanced to weight bearing as tolerated thereafter. There were no limits on range of motion and no brace was required.

Patient 2: Characteristics

The patient is a 53 year-old male who was referred to clinic for evaluation of right knee pain. Past medical history is significant for a motor vehicle crash in 1972 in which he sustained a right open femur fracture and right open tibia and fibula fractures. Treatment included skeletal traction for three months followed by casting. He was doing well until three years prior to presentation when he noted pain on the medial aspect of his right knee. The pain was worse with walking and rotational movements. Symptoms improved with stretching exercises. On physical exam, the patient had BMI of 24.4. He had an obvious varus deformity of the right leg. He walked with an antalgic gait on the right side. There was no swelling or deformity of the right knee. Range of motion was from 0 to 120 degrees on the right and from 0 to 130 degrees on the left. There was no anterior, posterior, varus, or valgus instability. Radiographs of the right femur demonstrated a healed malunion of a mid-shaft femur fracture without significant deformity. Radiographs of his right tibia and fibula showed a proximal tibial varus malunion with narrowing of the medial compartment joint space (Figure 4A). Standing full length alignment radiographs demonstrated a varus deformity of the right leg with a 22mm medial MAD. The LDFA measured 86 degrees, while the MPTA measured 83 degrees, indicating tibia vara (Figure 5A, 5B).

Patient 2: Surgical technique

BMAC was harvested using the same technique described previously. Diagnostic arthroscopy was then performed, revealing grade I chondromalacia of the patella. The trochlear cartilage was intact. There were no chondral changes in the lateral compartment. The lateral meniscus was intact. The medial compartment showed a degenerative tear in the posterior horn of the medial meniscus extending into the red-red zone, a full thickness cartilage defect of the medial femoral condyle measuring 15 mm by 10 mm (Figure 6A). A partial meniscectomy of the posterior horn of the medial meniscus was performed using an arthroscopic shaver and basket, leaving a stable rim of posterior horn. The medial femoral condyle lesion was microfractured with a 30-degree pick with holes spaced approximately 4 mm apart (Figure 6B).

An Esmarch bandage was used to exsanguinate the limb. The tourniquet was inflated to 250 mmHg. A 10 cm incision was made over the proximal medial tibia. Subperiosteal dissection was then performed to expose the medial proximal tibia. A pin was placed to mark the oblique osteotomy trajectory in the proximal tibia. The osteotomy was directed at the proximal tibia-fibular articulation with special attention to avoid the tibial tubercle. A microsagittal saw was used to create the osteotomy by following the guide wire in the manner described for patient

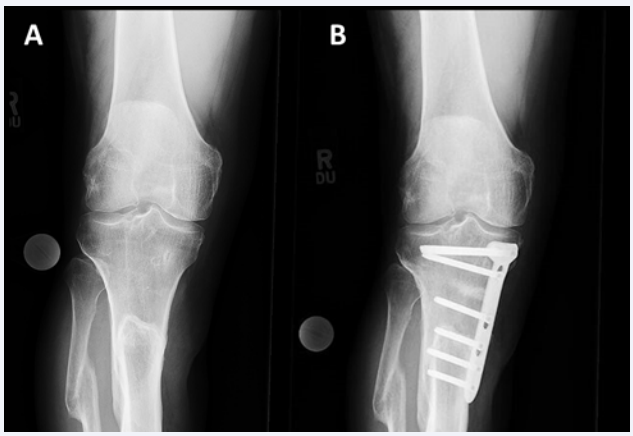

Figure 4 Preoperative anteroposterior left knee radiograph (A) of Patient 2 demonstrating joint space narrowing in the medial compartment and (B) post-operative radiograph demonstrating improved medial compartment joint space compared to pre-operative imaging.

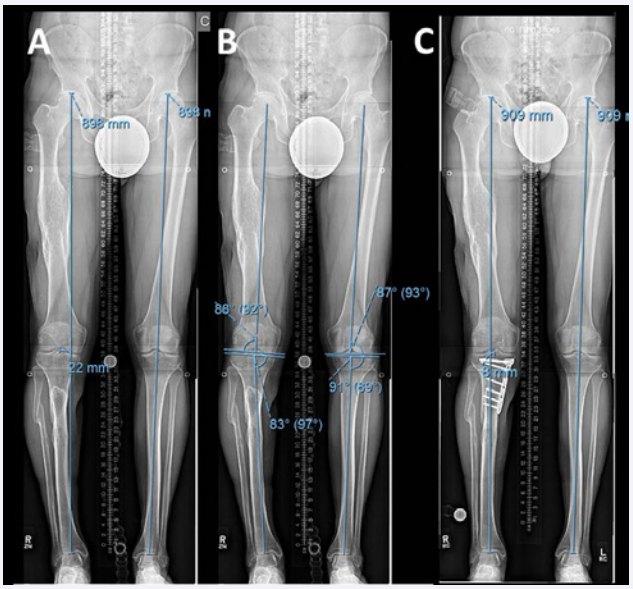

Figure 5 Standing full length alignment radiographs for Patient 2 demonstrating (A) varus deformity of the right lower extremity with a 22mm medial MAD; (B) the LDFA measured 86 degrees and the MPTA measured 83 degrees, indicating tibia vara; (C) a post-operative standing full length alignment radiograph showed that the mechanical axis was corrected to 8mm lateral postoperatively and the MPTA normalized.

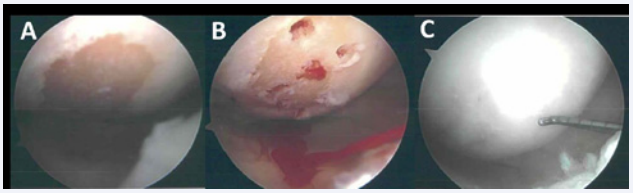

Figure 6 Arthroscopic images of Patient 2 showing (A) a 10 mm by 15 mm osteochondral defect of the medial femoral condyle, (B) post-microfracture of the defect, and (C) second look arthroscopy showed fill of the large full thickness defect at follow-up.

1. The lateral cortex was left intact. Laminar spreaders were used to distract the medial aspect of the osteotomy a total of 9 mm. The medial plate was applied and provisionally fixed in place while alignment was checked using an alignment rod extending from the center of the right hip to the right ankle. Once alignment was confirmed, four locking screws were placed in the proximal and distal segments. The proximal screws were unicortical while the distal segment screws were bicortical. The osteotomy was filled with freeze-dried allograft chips and demineralized bone matrix putty. A drain was placed and layered closure performed. Dry sterile dressings were applied and the tourniquet let down. The patient was allowed toe touch weight bearing with a 30 pound limit for the first 6 weeks and advanced to weight bearing as tolerated thereafter. There were no limits on range of motion and no brace was required.

RESULTS

Subjective patient-reported outcomes and objective outcomes were available for both patients. The Subjective Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire was completed by both patients preoperatively and at a minimum of two-years postoperatively [22]. Objective measures included pre- and postoperative radiographs and second look arthroscopy, which was performed at the time of routine removal of hardware. No complications were encountered in the first case. In the second case, the patient developed erythema and swelling around his surgical site concerning for a superficial soft tissue infection. He was prescribed an antibiotic regimen, which he did not take. Symptoms nevertheless resolved spontaneously and the remainder of his post-operative course was uneventful.

Patient 1

At two-year follow-up, the patient reported no pain. Range of motion improved from 0 to 110 degrees preoperatively to 0 to 125 degrees postoperatively on the operative knee. Subjective KOOS scores improved from 65.99 preoperatively to 79.91 at two-year follow-up. Anteroposterior radiographs showed improved joint space in the medial compartment (Figure 1B). Standing full-length alignment radiographs showed that the MAD improved from 31mm medial to 0 mm postoperatively, with normalization of MPTA (Figure 2C). Removal of hardware and second look arthroscopic examination was performed which showed cartilage defect fill at the microfracture site, with no areas of bare bone or residual cartilage defects (Figure 3C). There was one small area of fissuring on the medial femoral condyle, which was debrided and additional BMAC was added over the site.

Patient 2

At two-year follow-up, the patient reported mild but improved pain in the knee. Range of motion improved from 0 to 120 degrees preoperatively to 0 to 125 degrees postoperatively on the operative knee. The subjective KOOS score improved from 24.88 preoperatively to 39.63 at two years postoperatively. Anteroposterior radiographs showed improved joint space in the medial compartment (Figure 4B). Standing full-length alignment radiographs showed that the mechanical axis was corrected from 22mm medial to 8mm lateral postoperatively, with normalization of the MPTA (Figure 5C). Removal of hardware and second look arthroscopic examination was performed which showed in-growth with articular cartilage over the area previously treated with microfracture for a full thickness cartilage defect (Figure 6C).

DISCUSSION

The most important findings in these two cases are that combined HTO with microfracture and BMAC augmentation resulted in a neutral to overcorrected mechanical axis, cartilage fill, stable tissue quality, and improved KOOS scores in two patients with large symptomatic full thickness chondral lesions of the medial femoral condyle. These results demonstrate that joint preserving techniques may be efficacious even in patients with very large and even uncontained cartilage defects. As the population continues to age, young and middle aged patients with varus deformity and medial compartment osteoarthritis leading to pain and disability will increasingly demand to maintain active lifestyles [23,24], and HTO with microfracture may serve as an excellent tool in joint preservation.

In addition to improving pain and function, an important goal for many patients who choose joint preserving surgery is delaying conversion to UKA or TKA. Joint preserving surgery for tibia vara can be successfully performed with either internal or external fixation techniques [25,26]. With correction of tibial deformity, a future arthroplasty may even be simplified (i.e, instead of needing a TKR, the patient may become a candidate for a UKR) [27]. HTO has also been shown to offer improved cost effectiveness compared to UKA or TKA. A recent study by Konopka et al., showed that at a willingness-to-pay threshold of $50,000 per quality adjusted life year, high tibial osteotomy is cost-effective 57% of the time, total knee arthroplasty 24%, and unicompartmental knee arthroplasty 19% [28].

Survivorship following HTO has been well studied by others. Schuster et al., reported outcomes for 91 knees with a minimum follow-up of 5 years following open wedge HTO and microfracture for patients with severe (Kellgren-Lawrence grade 3 and 4 [29]) osteoarthritis and varus malalignment [20]. Diagnostic arthroscopy was performed at the time of removal of hardware in 80 patients (87.9%) at a mean of 1.5 years after surgery. Results showed a 95.2% survival rate at 5 years, with 3 conversions to UKA and 1 conversion to TKA. A study by Sterett et al., reported outcomes for 106 knees with a minimum follow-up of 7 years following HTO and microfracture. Lesion size and severity of varus deformity were not reported. Results showed 97% survivorship at 5 years and 91% survivorship at 7 years [21]. Minzlaff et al., reported results for 86 patients who underwent joint preserving surgery consisting of HTO and osteochondral autologous transfer [19]. Results showed a mean survival rate of 90.1% at 8.5 years after surgery. Results of this study showed no conversion to total knee arthroplasty at two year follow-up.

A study by Saw et al., performed histological examination of cartilage quality in 8 patients who underwent HTO, microfracture, and injection of autologous peripheral blood stem cells (PBSCs) with hyaluronic acid [30]. Injections with PBSCs were performed in the operating room and at one week intervals for the next 5 weeks. Injections were also given at 6, 12, and 18 months after the index surgery. All patients underwent second look arthroscopy and cartilage biopsy. On second look arthroscopy, there was satisfactory healing found in all patients. The International Cartilage Research Society (ICRS) Visual Assessment Scale II histological scores were used to evaluate biopsy specimens. Normal articular cartilage was used for comparison. Biopsy specimens from the regenerated articular cartilage scored within 95% of scores of normal articular cartilage. Together these results show that joint preserving techniques consisting of HTO, microfracture, and biologic augmentation yield not only excellent fill of articular cartilage defects, but also high quality repair tissue that closely mirrors normal articular cartilage. While cartilage biopsies were not performed in the present report, fill of the cartilage defects was observed in our two patients.

The effect of biologic augmentation of microfracture with BMAC harvested from the iliac crest has previously described but outcomes are underreported [7,11,31]. Much preliminary work has been performed in large animal models. Fortier et al used an equine model to study the effect of concentrated bone marrow aspirate augmentation over microfracture compared to microfracture alone for treatment of large (15 mm diameter) full thickness chondral defects created in the lateral trochlear ridge [10]. Second look arthroscopy was performed at 3-months and the horses were sacrificed at 8-months postoperatively. Results showed that BMAC increased fill and integration, had greater type II collagen content, and greater glycosaminoglycan content. McIlwrath et al., also used an equine model to compare microfracture alone versus microfracture plus bone marrow-derived mesenchymal stem cells injected at 1 month after microfracture [11]. Results showed increased aggrecan content and tissue firmness in the group that received microfracture augmented by stem cells. While results of animal model studies suggest improved tissue quality and integration with stem cell augmentation, additional study is needed to evaluate similar parameters among human subjects.

This case report has several limitations. The report presents two cases and therefore results may not be generalizable across a larger cohort of patients. Both patients were male, which may preclude translation of results to a female patient cohort. Outcomes are reported at a minimum of 2-years follow-up. Additional follow-up at mid- and long-term intervals is required to assess the durability of the cartilage resurfacing (microfracture) and the success in delaying or preventing conversion to knee arthroplasty. Additionally, the second patient's lower KOOS score may have been confounded by extensive soft tissue trauma at the time of the index injury. Future prospective comparative studies are needed with a control group to further evaluate the efficacy of HTO and microfracture compared to HTO and other chondral repair or transplantation procedures for treatment of patients with large full thickness chondral lesions.

CONCLUSIONS

Results of this report demonstrate that joint preserving techniques utilizing high tibial osteotomy and microfracture augmented with bone marrow aspirate concentrate successfully restored a neutral mechanical axis and resulted in improved subjective outcome scores in two patients with large symptomatic grade IV chondral lesions of the medial femoral condyle. Joint preservation through HTO and microfracture may serve as a reliable joint preservation procedure in the treatment of OA in the increasingly younger population.

REFERENCES

1. Coventry MB. Osteotomy of the Upper Portion of the Tibia for Degenerative Arthritis of the Knee: A Preliminary Report. J Bone Joint Surg Am. 1965; 47: 984-990.
2. Hamdy RC, Bernstein MA, Fragomen AT, Rozbruch SR. What's New in Limb Lengthening and Deformity Correction. J Bone Joint Surg Am. 2016; 98: 1408-1415.
3. Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Joint Surg Am. 1987; 69: 332-354.
4. Jackson JP, Waugh W, Green JP. High tibial osteotomy for osteoarthritis of the knee. J Bone Joint Surg Br. 1969; 51: 88-94.
5. Maquet P. Valgus osteotomy for osteoarthritis of the knee. Clin Orthop Relat Res. 1976; 143-148.
6. Nwachukwu BU, McCormick FM, Schairer WW, Frank RM, Provencher

MT, Roche MW. Unicompartmental knee arthroplasty versus high tibial osteotomy: United States practice patterns for the surgical treatment of unicompartmental arthritis. J Arthroplasty. 2014; 29: 1586-1589.

7. Gigante A, Cecconi S, Calcagno S, Busilacchi A, Enea D. Arthroscopic knee cartilage repair with covered microfracture and bone marrow concentrate. Arthrosc Tech. 2012; 1: e175-180.

8. Harris JD, Hussey K, Wilson H, Pilz K, Gupta AK, Gomoll A, et al. Biological knee reconstruction for combined malalignment, meniscal deficiency, and articular cartilage disease. Arthroscopy. 2015; 31: 275-82.

9. Mazor M, Lespessailles E, Coursier R, Daniellou R, Best TM, Toumi H. Mesenchymal stem-cell potential in cartilage repair: an update. J Cell Mol Med. 2014; 18: 2340-2350.

10. Fortier LA, Potter HG, Rickey EJ, Schnabel LV, Foo LF, Chong LR, et al. Concentrated bone marrow aspirate improves full-thickness cartilage repair compared with microfracture in the equine model. J Bone Joint Surg Am. 2010; 92: 1927-1937.

11. McIlwraith CW, Frisbie DD, Rodkey WG, Kisiday JD, Werpy NM, Kawcak CE, et al. Evaluation of intra-articular mesenchymal stem cells to augment healing of microfractured chondral defects. Arthroscopy. 2011; 27: 1552-1561.

12. Faschingbauer M, Nelitz M, Urlaub S, Reichel H, Dornacher D. Return to work and sporting activities after high tibial osteotomy. Int Orthop. 2015; 39: 1527-1534.

13. Ferruzzi A, Buda R, Cavallo M, Timoncini A, Natali S, Giannini S. Cartilage repair procedures associated with high tibial osteotomy in varus knees: clinical results at 11 years' follow-up. Knee. 2014; 21: 445-450.

14. Harris JD, McNeilan R, Siston RA, Flanigan DC. Survival and clinical outcome of isolated high tibial osteotomy and combined biological knee reconstruction. Knee. 2013; 20: 154-161.

15. LaPrade RF, Spiridonov SI, Nystrom LM, Jansson KS. Prospective outcomes of young and middle-aged adults with medial compartment osteoarthritis treated with a proximal tibial opening wedge osteotomy. Arthroscopy. 2012; 28: 354-364.

16. Matsunaga D, Akizuki S, Takizawa T, Yamazaki I, Kuraishi J. Repair of articular cartilage and clinical outcome after osteotomy with microfracture or abrasion arthroplasty for medial gonarthrosis. Knee. 2007; 14: 465-471.

17. Pascale W, Luraghi S, Perico L, Pascale V. Do microfractures improve high tibial osteotomy outcome? Orthopedics. 2011; 34: e251-255.

18. Konopka JF, Gomoll AH, Thornhill TS, Katz JN, Losina E. The cost-effectiveness of surgical treatment of medial unicompartmental knee osteoarthritis in younger patients: a computer model-based evaluation. J Bone Joint Surg Am. 2015; 10: 807-817.

19. Minzlaff P, Feucht MJ, Saier T, Schuster T, Braun S, Imhoff AB, et al. Osteochondral autologous transfer combined with valgus high tibial osteotomy: long-term results and survivorship analysis. Am J Sports Med. 2013; 41: 2325-2332.

20. Schuster P, Schulz M, Mayer P, Schlumberger M, Immendoerfer M, Richter J. Open-Wedge High Tibial Osteotomy and Combined Abrasion/Microfracture in Severe Medial Osteoarthritis and Varus Malalignment: 5-Year Results and Arthroscopic Findings After 2 Years. Arthroscopy. 2015; 31: 1279-1288.

21. Sterett WI, Steadman JR, Huang MJ, Matheny LM, Briggs KK. Chondral resurfacing and high tibial osteotomy in the varus knee: survivorship analysis. Am J Sports Med. 2010; 38: 1420-1424.

22. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS)--development of a self-administered outcome measure. J Orthop Sports Phys Ther. 1998; 28: 88-96.

23. Bonasia DE, Dettoni F, Sito G, Blonna D, Marmotti A, Bruzzone M, et al. Medial opening wedge high tibial osteotomy for medial compartment overload/arthritis in the varus knee: prognostic factors. Am J Sports Med. 2014; 42: 690-698.

24. Scordino LE, DeBerardino TM. Surgical treatment of osteoarthritis in the middle-aged athlete: new horizons in high tibial osteotomies. Sports Med Arthrosc. 2013; 21: 47-51.

25. Ashfaq K, Fragomen AT, Nguyen JT, Rozbruch SR. Correction of proximal tibia varus with external fixation. J Knee Surg. 2012; 25: 375-384.

26. Rozbruch SR, Segal K, Ilizarov S, Fragomen AT, Ilizarov G. Does the Taylor Spatial Frame accurately correct tibial deformities? Clin Orthop Relat Res. 2010; 468: 1352-1361.

27. Valenzuela GA, Jacobson NA, Buzas D, Koreckij TD, Valenzuela RG, Teitge RA. Unicompartmental knee replacement after high tibial osteotomy: Invalidating a contraindication. Bone Joint J. 2013; 95-B: 1348-1353.

28. Konopka JF, Gomoll AH, Thornhill TS, Katz JN, Losina E. The cost-effectiveness of surgical treatment of medial unicompartmental knee osteoarthritis in younger patients: a computer model-based evaluation. J Bone Joint Surg Am. 2015; 97: 807-817.

29. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957; 16: 494-502.

30. Saw KY, Anz A, Jee CS, Ng RC, Mohtarrudin N, Ragavanaidu K. High Tibial Osteotomy in Combination With Chondrogenesis After Stem Cell Therapy: A Histologic Report of 8 Cases. Arthroscopy. 2015; 31: 1909-1920.

31. De Girolamo L, Bertolini G, Cervellin M, Sozzi G, Volpi P. Treatment of chondral defects of the knee with one step matrix-assisted technique enhanced by autologous concentrated bone marrow: in vitro characterisation of mesenchymal stem cells from iliac crest and subchondral bone. Injury. 2010; 41: 1172-1177.

Cite this article

James EW, Corpus KT, Fragomen AT, Rozbruch SR (2017) Opening Wedge High Tibial Osteotomy, Microfracture, and Bone Marrow Aspirate Concentrate for Treatment of Varus Deformity and Osteoarthritis of the Knee. Ann Sports Med Res 4(2): 1106.