



International Journal of Orthopedics: Research & Therapy

Case Report

A Case Report of Spontaneous Osteonecrosis of the Knee with 7 Years of Follow-up -

George I Vasileiadis¹, Krit Boontanapibul^{2,3}, Matthew A. Follett³, Alvin T Li³, Ioannis C Sioutis⁴ and Derek F Amanatullah^{3*}

¹Departments of Orthopedic Surgery and Physical Medicine and Rehabilitation Clinic, University of Ioannina Medical School, Ioannina, Greece

²Department of Orthopaedics, Chulabhorn International College of Medicine, Thammasat University, Pathum Thani, Thailand

³Department of Orthopaedic Surgery, Stanford Hospital and Clinics, Redwood City, California, United States of America

⁴Department of Physical Medicine and Rehabilitation, Asklepion General Hospital of Voula, Athens, Greece

***Address for Correspondence:** Derek F. Amanatullah, Department of Orthopaedic Surgery, Stanford Hospital and Clinics, 450 Broadway Street, C402, Redwood City, California, CA 94063-6342, Tel: +650-723-2257/ +650-723-5643; E-mail: dfa@stanford.edu

Submitted: 11 August 2019; Approved: 23 September 2019; Published: 28 September 2019

Cite this article: Vasileiadis GI, Boontanapibul K, Follett MA, Li AT, Sioutis IC, Amanatullah DF. A Case Report of Spontaneous Osteonecrosis of the Knee with 7 Years of Follow-up. Int J Ortho Res Ther. 2019;3(1): 006-0010.

Copyright: © 2019 Vasileiadis GI, et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ABSTRACT

Introduction: Spontaneous Osteonecrosis of the Knee (SONK) is a devastating and debilitating disease that mainly afflicts the elderly. A conservative approach may forgo the need for surgical intervention. This case report describes an orthopaedic patient diagnosed with SONK. After five months of conservative treatment, the patient was able to walk without pain and remained clinically stable for seven years.

Case Presentation: A 49-year-old male patient diagnosed with SONK of the left knee elected to undergo conservative management in lieu of surgical intervention. Seven years later the patient's symptoms and MRI demonstrate a dramatic improvement.

Conclusion: Current surgical procedures have had mixed results for treating SONK. All physicians, especially orthopedic surgeons, should be aware of expected outcomes for surgical intervention in SONK patients. Initial conservative management may be preferable to surgical intervention in some cases

Keywords: Spontaneous osteonecrosis of the knee; SONK; Conservative treatment; Surgical treatment

INTRODUCTION

Osteonecrosis of the knee is a debilitating condition characterized by knee pain and bone marrow lesions, typically affecting both distal femoral condyles and/or the proximal tibia. It can be further delineated into two primary categories: Spontaneous Osteonecrosis of the Knee (SONK) and secondary osteonecrosis. SONK is particularly common in elderly females, affecting over 9% of patients over the age of 65 years [1-3]. SONK classically presents with acute onset of intense pain isolated to the medial femoral condyle [4]. The condition rarely occurs in lateral femoral condyle, tibial plateaus, and patella [5-7]. Additionally, effusion and pain may limit range of motion [8,9]. The etiology of SONK is unclear, but it may originate from subchondral insufficiency or stress fracture [10,11]. In contrast, secondary osteonecrosis tends to present with gradually worsening pain in the medial and lateral condyles bilaterally, and other large joint involvement, particularly the hip [12]. Secondary osteonecrosis is typically found in patients under 55 years of age with risk factors including corticosteroid use, sickle-cell disease, alcohol consumption, Caisson's disease, Gaucher's disease, rheumatoid arthritis, and systemic lupus erythematosus [1,2]. In secondary osteonecrosis, ischemia and osteonecrosis lead to subchondral fracture, cartilage degeneration, and eventual subchondral collapse of the affected condyles [9,12].

Available treatment options differ between SONK and secondary osteonecrosis. In early stages or lesions smaller than 3.5 cm², SONK has been successfully managed with conservative treatment [8,13]. This consists of protected weight bearing with crutches, analgesics, non-steroidal anti-inflammatory drugs, and physical therapy. In refractory SONK and secondary osteonecrotic lesions larger than 5 cm², necrotic segments may result in subchondral collapse or extension of the lesion [14,15]. This presentation of SONK, similar to secondary osteonecrosis, is often treated with invasive surgical procedures, including core decompression with or without bone grafting, arthroscopy, osteochondral grafting, high tibial osteotomy, or arthroplasty [2,16]. This case report describes an orthopaedic patient diagnosed with SONK. After five months of conservative treatment, the patient was able to walk without pain, and remains clinically stable for seven years.

CASE PRESENTATION

A 49-year-old man presented to the outpatient clinic on January 2009 complaining of excruciating pain of both the medial and lateral femoral condyles of his left knee. His pain began in the medial condyle one month prior, increasing in intensity and spreading to the lateral

condyle 3 to 4 days before he sought medical attention. This pain was intermittent during normal walking and aggravated by climbing up or down stairs. The patient reported no recent injury to his knee and is sedentary at home and at work. He has an unremarkable medical history, but smokes 20 cigarettes per day.

On physical examination, the patient was afebrile with stable vital signs as well as a normal general appearance. Focused examination revealed slight effusion of the left knee without noticeable muscular atrophy or skin discoloration. Palpation of the medial femoral condyle elicited pain radiating to the lateral femoral condyle, especially during knee flexion. The knee was stable to varus and valgus stress at 30° of extension. The patient had a negative Lachman's test, a negative posterior drawer, a negative dial test, as well as an intermittently positive McMurray's test. Strength testing was normal at 5/5 for both knee flexion and extension, but knee flexion was restricted by pain. Sensation was intact to light touch in all nerve distributions. There was a palpable dorsalis pedis pulse. No long track signs or distal edema were detected.

Blood tests revealed no autoimmune or infectious disease. Radiographs of the knee were negative for gross involvement of the bone or misalignment (Figure 1). After six weeks of analgesic and anti-inflammatory therapy, symptoms persisted and worsened. At this time, an MRI was obtained (Figure 2).

With a working diagnosis of SONK, conservative treatment was initiated with the patient's consent. His treatment regimen consisted of crutch training to reducing weight bearing on the knee, physical therapy focused on strengthening the quadriceps and hamstring muscles, and non-steroidal anti-inflammatory drugs. After 5 months of conservative management, the patient's symptoms had resolved completely. A follow-up MRI, 7 years later, revealed marked improvement in the osteonecrotic lesion (Figure 3).

DISCUSSION

Etiology and pathophysiology

In spite of its prevalence, the etiology of SONK is poorly understood. No clear medical or genetic risk factors have been associated with SONK. SONK most frequently affects females over 65 years of age. Several possible causes have been proposed, including subchondral stress in osteopenic bone with insufficiency fractures [10,11,17] and meniscal tears [18-20]. Chronic or minor subchondral trauma in osteoporotic bone could induce microfractures, leading to fluid accumulation in the intracondylar space, increasing intraosseous pressure, leading to vascular compromise, subsequent focal osseous

ischemia, and finally osteonecrosis [11]. Similarly, meniscal lesions have been associated with SONK, where loss of meniscal cartilage increases subchondral stress, leading to microfractures and necrotic bone in the same way [19,20]. SONK may not be a true osteonecrosis, as some authors have reported finding no necrotic tissue in affected condyles of patients diagnosed with SONK [3,20,21].

DIAGNOSIS

SONK can be diagnosed based on symptomatic and radiological criteria. The most characteristic symptoms include unilateral acute onset of pain isolated to the medial femoral condyle. The lateral condyle, tibial plateau, and patella are also susceptible. Small to moderate effusion along with tenderness over the affected area is typical. Flexion contracture and decreased range of motion secondary to pain or effusion may also be present. In contrast, secondary osteonecrosis tends to present with gradual onset of pain, and is frequently bilateral [9,22].

Plain radiograph is an inexpensive tool for initial evaluation and monitoring disease progression; however, it often does not show any abnormalities in the early stages of osteonecrosis [4,23]. Bone scintigraphy and Magnetic Resonance Imaging (MRI) are far more effective for differential diagnosis of osteonecrosis. Greyson et al. described a three-stage scintigraphic staging study for spontaneous osteonecrosis of the femoral condyle [24]. Following these criteria, markedly increased focal activity in all three phases is diagnostic for acute osteonecrosis. Normal activity in the flow-phase and increased activity in blood-pool and delayed phases is diagnostic for secondary osteonecrosis. MRI is the imaging modality of choice because of high sensitivity in detection of bone edema [25] and ability to evaluate meniscal and chondral pathology. SONK presents with an MRI pattern of subcortical focal loss of signal, along with homolateral meniscal degeneration or tearing, and focal deformity of the subchondral plate. No demarcation rim is typically observed. In contrast, secondary osteonecrosis frequently presents with the demarcation rim, and infrequent homolateral meniscal lesions and focal deformity of the subchondral bone plate [22]. Therefore, MRI and bone scintigraphy allow differential diagnosis of osteonecrosis, distinguishing it from different pathologies such as primary osteoarthritis, meniscal tears, and pes anserinus bursitis.

In our case, the symptom that led the patient to seek medical attention was sudden excruciating pain in the left knee. Plain radiographs revealed no abnormalities. The first abnormalities were found with an initial MRI, which revealed bone marrow edema and a minute fracture in the joint surface of the medial condyle. Subsequent MRI revealed enlargement of the fracture ($2.2 \times 3 \text{ cm}^2$).

Treatment: Non-operative

In asymptomatic patients, initial treatments for SONK and secondary osteonecrosis are similarly conservative [9]. Therapy includes reduced weight-bearing using crutches or a walker, non-steroidal anti-inflammatory drugs, and physical therapy focused on strengthening the quadriceps and hamstring muscles. The goal of conservative treatment is to prevent progression of the disease to subchondral collapse. Even in symptomatic patients, continuation of conservative treatment is effective for SONK patients. Prognosis of non-operative treatment depends on lesion size. Smaller lesions (less than 3.5 cm^2) tend to resolve completely, while large lesions (greater than 5 cm^2 or involving more than 40% of the condyle) tend to progress to subchondral collapse [14,15,26].

Treatment: Arthroscopic debridement

Arthroscopy allows visualization of the affected areas, which is particularly useful for visualization when there is a question of lesion size or coexisting damage (e.g., meniscal tear). Miller et al. performed arthroscopic debridement on five patients with idiopathic osteonecrosis. At a mean follow-up time of 31 months, four out of

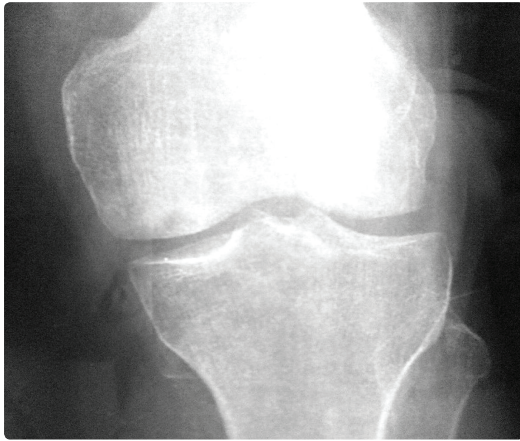


Figure 1: Anterior to posterior radiograph of left knee at the time of presentation.

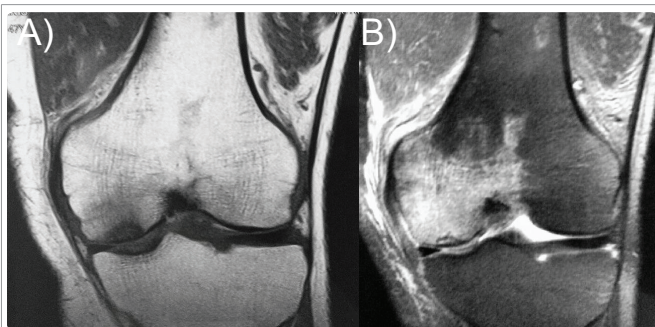


Figure 2: T1-weighted (A) and T2-weighted (B) MRI of left knee after six weeks of analgesic and non-steroidal anti-inflammatory treatment. At this time, the patient reported that the pain had progressed and worsened.



Figure 3: T1-weighted MRI of left knee at seven years follow-up after five months of non-operative treatment.

five patients were rated good post-operatively based on the Hospital for Special Surgery Rating System. The average pre-operative score was 52 points and post-operative score was 82 points [27].

Treatment: Core decompression

The principle behind core decompression is reduction of interosseous pressure via surgical extra-articular drilling of the affected condyle, promoting restoration of adequate circulation. Core decompression is a more conservative approach, which may delay the need for total knee arthroplasty. Forst et al. performed this procedure and reported immediate relief of pain in 15 out of 16 patients [28]. At 36 months follow-up, MRI confirmed successful normalization of bone marrow signal. The authors recommended this procedure for early osteonecrosis prior to flattening of the femoral condyle.

In secondary osteonecrosis, core decompression is similarly effective in early stages of the disease. Mont et al. compared core decompression with non-operative treatment in 79 knees. They performed core decompression on 47 knees with Ficat and Arlet stage I to stage III secondary osteonecrosis. At a mean follow-up time of 11 years, 73% of patients had good to excellent outcomes based on Knee Society Scores of 80 points or greater. Radiographs showed progression to Ficat and Arlet stage III or IV in 36% of core decompression knees, as opposed to 75% of nonoperative knees [29].

In a similar procedure, Goodman and Hwang investigated the efficacy of local debridement with osteoprogenitor cell grafting in twelve patients with secondary osteonecrosis of the distal femoral condyle. The premise of the study was to correct the biological deficiency of live osteoprogenitor cells in the subchondral and metaphyseal areas of necrotic femoral condyle. This procedure involved open debridement of the osteonecrotic lesion and drilling in at multiple angles, excising easily accessible loose necrotic bone. The defect was then filled with concentrated bone marrow osteoprogenitor cells harvested from the iliac crest. At an average follow-up time of 5 years, Knee Society Score averaged 87 points, and Knee Function Score averaged 85 points. The investigators recommended this procedure for young patients with secondary osteonecrosis of the knee prior to collapse of the femoral condyle [30].

Treatment: Osteochondral allografts and autologous osteochondral transplantation

Osteochondral repair may be used for patients for whom conservative treatment has failed. In the past, Bayne et al. attempted allografts for 6 SONK patients and 3 corticosteroid-induced secondary osteonecrosis patients. Of these, no secondary osteonecrosis graft succeeded and only one SONK graft was successful [31]. The authors suspected that continued use of corticosteroids led to poor vascularization of the graft and subsequent subsidence in the secondary graft procedures. For SONK, it was hypothesized that the poor compliance of elderly patients resulted in allograft fragmentation.

A more promising alternative has been autologous osteochondral transplantation. This treatment relies on transplanting articular cartilage with subchondral bone from less weight-bearing areas to the affected areas. The goal of osteochondral transplantation is to fill the affected area with cylindrical osteochondral allografts to form a congruent hyaline cartilage covered surface. Hangody et al. reported good to excellent outcomes in 92% of 789 patients treated with femoral condylar implants [32]. Their results were calculated

based on modified Hospital for Special Surgery, modified Cincinnati, Lysholm, and International Cartilage Repair society scores.

Treatment: High tibial osteotomy

High tibial osteotomy involves making a transverse cut in the proximal tibial metaphysis and removing a wedge of bone to change the geometry of the lower limb. This procedure seeks to change the geometry of the limb in order to reduce the load on the affected condyle. High tibial osteotomy has had promising results for SONK patients. Aglietti et al. followed 31 patients treated with high tibial osteotomy, 21 of which had also undergone ancillary bone grafting. At a mean follow-up of 6.2 years, 87% of these patients had successful outcomes, and only two knees required arthroplasty [14]. Use of high tibial osteotomy is limited in secondary osteonecrosis because these patients tend to have tibial or bicondylar femoral involvement [3,9].

Treatment: Unicondylar arthroplasty

Unicondylar arthroplasty has been used with success in SONK due to the tendency of the disease to be confined to one condyle. This procedure involves replacing the affected femoral condyle and associated tibial articular surface. In contrast, this procedure is not generally recommended for secondary osteonecrosis if it involves both condyles. In a study of 41 SONK patients, Chalmers et al. reported an 93% success rate in unicondylar knee arthroplasty for an isolated compartment at both five and ten years follow-up [33]. This treatment has the advantage of rapid post-operational recovery and minimizing effects on the cruciate ligaments, patella, and the other compartment of the knee. A recent meta-analysis study also reported that cemented medial unicondylar knee arthroplasty has the same clinical and survival outcome as medial compartment knee osteoarthritis when treating SONK [34].

Treatment: Total knee arthroplasty

Total knee arthroplasty is reserved for late-stage osteonecrosis when patients are in severe pain that has not responded to other interventions. It is indicated for late-stage secondary osteonecrosis with degenerative changes, patients with severe pain, and those with functional disability. This procedure involves replacing the patient's femoral and tibial articular surfaces. Myers et al. reviewed the outcomes of total knee arthroplasty on 148 knees with SONK and 150 knees with secondary osteonecrosis. They reported successful outcomes in 92% of SONK cases and 74% of secondary osteonecrosis cases based on Knee Society and Hospital for Special Surgery scores [16].

CONCLUSION

We describe a case of successful conservative treatment of SONK. In spite of improvements in technique since 1985, it is clear that surgical treatment of osteonecrosis is not always met with success. It is important to differentiate between SONK and secondary osteonecrosis. Regarding the medical therapy of osteonecrosis of the knee, treatment is similar for both SONK and secondary osteonecrosis as long as the patient is asymptomatic. This encompasses a conservative regimen of partial weight bearing with crutches or a walker, non-steroidal anti-inflammatory medications, and physical therapy focusing on strengthening the quadriceps and hamstrings. However, when the patient is symptomatic, treatment options differ. Conservative measures should be the first consideration for SONK to minimize invasive procedures and optimize long-term outcomes for patients.

CLINICAL MESSAGE

The current surgical procedures available for treating SONK have mixed results. All physicians, especially orthopedic surgeons, should be aware of the expected outcomes for surgical intervention in patients with SONK. Initial conservative management may be preferable to surgical intervention in some cases.

ACKNOWLEDGEMENTS AND FUNDING

No outside funding was required to conduct this case report. Additionally, this case report was Institutional Review Board (IRB) exempt.

REFERENCES

- Pape D, Seil R, Fritsch E, Rupp S, Kohn D. Prevalence of spontaneous osteonecrosis of the medial femoral condyle in elderly patients. *Knee Surg Sports Traumatol Arthrosc.* 2002; 10: 233-240. <http://bit.ly/2mffx3W>
- Karim AR, Cherian JJ, Jauregui JJ, Pierce T, Mont MA. Osteonecrosis of the knee: review. *Ann Transl Med.* 2015; 3: 6. <http://bit.ly/2kHEgxd>
- Kattapuram TM, Kattapuram SV. Spontaneous osteonecrosis of the knee. *Eur J Radiol.* 2008; 67: 42-48. <http://bit.ly/2lgT1aH>
- al-Rowaih A, Bjorkengren A, Egund N, Lindstrand A, Wingstrand H, Thorngren KG. Size of osteonecrosis of the knee. *Clin Orthop Relat Res.* 1993; 287: 68-75. <http://bit.ly/2kHBzvb>
- Lotke PA, Abend JA, Ecker ML. The treatment of osteonecrosis of the medial femoral condyle. *Clin Orthop Relat Res.* 1982; 171: 109-116. <http://bit.ly/2lfVMJb>
- LaPrade RF, Noffsinger MA. Idiopathic osteonecrosis of the patella: an unusual cause of pain in the knee. A case report. *J Bone Joint Surg Am.* 1990; 72: 1414-1418. <http://bit.ly/2mfMfSG>
- Ohdera T, Miyagi S, Tokunaga M, Yoshimoto E, Matsuda S, Ikari H. Spontaneous osteonecrosis of the lateral femoral condyle of the knee: a report of 11 cases. *Arch Orthop Trauma Surg.* 2008; 128: 825-831. <http://bit.ly/2mDHbHR>
- Yates PJ, Calder JD, Stranks GJ, Conn KS, Peppercorn D, Thomas NP. Early MRI diagnosis and non-surgical management of spontaneous osteonecrosis of the knee. *Knee.* 2007; 14: 112-116. <http://bit.ly/2lgOzsv>
- Zywił MG, McGrath MS, Seyler TM, Marker DR, Bonutti PM, Mont MA. Osteonecrosis of the knee: a review of three disorders. *Orthop Clin North Am.* 2009; 40: 193-211. <http://bit.ly/2kHLEZw>
- Mears SC, McCarthy EF, Jones LC, Hungerford DS, Mont MA. Characterization and pathological characteristics of spontaneous osteonecrosis of the knee. *The Iowa orthopaedic journal.* 2009; 29: 38-42. <http://bit.ly/2l3zevo>
- Yamamoto T, Bullough PG. Spontaneous osteonecrosis of the knee: the result of subchondral insufficiency fracture. *J Bone Joint Surg Am.* 2000; 82: 858-866. <http://bit.ly/2mmIGtN>
- Mont MA, Baumgarten KM, Rifai A, Bluemke DA, Jones LC, Hungerford DS. A traumatic osteonecrosis of the knee. *J Bone Joint Surg Am.* 2000; 82: 1279-1290. <http://bit.ly/2mkUvAG>
- Woehnl ANQ, Costa C. Osteonecrosis of the knee. *Orthopaedic Knowledge Online Journal.* 2012; 10.
- Aglietti P, Insall JN, Buzzi R, Deschamps G. Idiopathic osteonecrosis of the knee. Aetiology, prognosis and treatment. *J Bone Joint Surg Br.* 1983; 65: 588-597. <http://bit.ly/2mm1mtC>
- Mont MA, Marker DR, Zywił MG, Carrino JA. Osteonecrosis of the knee and related conditions. *J Am Acad Orthop Surg.* 2011; 19: 482-494. <http://bit.ly/2mkhD2A>
- Myers TG, Cui Q, Kuskowski M, Mihalko WM, Saleh KJ. Outcomes of total and unicompartmental knee arthroplasty for secondary and spontaneous osteonecrosis of the knee. *J Bone Joint Surg Am.* 2006; 88: 76-82. <http://bit.ly/2mfTfio>
- Akamatsu Y, Mitsugi N, Hayashi T, Kobayashi H, Saito T. Low bone mineral density is associated with the onset of spontaneous osteonecrosis of the knee. *Acta Orthop.* 2012; 83: 249-255. <http://bit.ly/2ldytj>
- Brahme SK, Fox JM, Ferkel RD, Friedman MJ, Flannigan BD, Resnick DL. Osteonecrosis of the knee after arthroscopic surgery: diagnosis with MR imaging. *Radiology.* 1991; 178: 851-853. <http://bit.ly/2mJTzG2>
- Robertson DD, Armfield DR, Towers JD, Irrgang JJ, Maloney WJ, Harner CD. Meniscal root injury and spontaneous osteonecrosis of the knee: an observation. *J Bone Joint Surg Br.* 2009; 91: 190-195. <http://bit.ly/2mLgJw9>
- Yasuda T, Ota S, Fujita S, Onishi E, Iwaki K, Yamamoto H. Association between medial meniscus extrusion and spontaneous osteonecrosis of the knee. *Int J Rheum Dis.* 2018; 21: 2104-2111. <http://bit.ly/2mf5iN2>
- Takeda M, Higuchi H, Kimura M, Kobayashi Y, Terauchi M, Takagishi K. Spontaneous osteonecrosis of the knee: histopathological differences between early and progressive cases. *J Bone Joint Surg Br.* 2008; 90: 324-329. <http://bit.ly/2kMUc1q>
- Narvaez J, Narvaez JA, Rodriguez-Moreno J, Roig-Escofet D. Osteonecrosis of the knee: differences among idiopathic and secondary types. *Rheumatology (Oxford).* 2000; 39: 982-989. <http://bit.ly/2l0X9LX>
- Pollack MS, Dalinka MK, Kressel HY, Lotke PA, Spritzer CE. Magnetic resonance imaging in the evaluation of suspected osteonecrosis of the knee. *Skeletal Radiol.* 1987; 16: 121-127. <http://bit.ly/2lffqamX>
- Greyson ND, Lotem MM, Gross AE, Houpt JB. Radionuclide evaluation of spontaneous femoral osteonecrosis. *Radiology.* 1982; 142: 729-735. <http://bit.ly/2mKNDNq>
- Fotiadou A, Karantanas A. Acute nontraumatic adult knee pain: the role of MR imaging. *Radiol Med.* 2009; 114: 437-447. <http://bit.ly/2l4poJJ>
- Jurés J, Lindstrand A, Geijer M, Robertsson O, Tägil M. The natural course of Spontaneous Osteonecrosis of the Knee (SPONK): a 1- to 27-year follow-up of 40 patients. *Acta Orthop.* 2013; 84: 410-414. <http://bit.ly/2mLLD7L>
- Miller GK, Maylahn DJ, Drennan DB. The treatment of idiopathic osteonecrosis of the medial femoral condyle with arthroscopic debridement. *Arthroscopy.* 1986; 2: 21-29. <http://bit.ly/2kHRH09>
- Forst J, Forst R, Heller KD, Adam G. Spontaneous osteonecrosis of the femoral condyle: causal treatment by early core decompression. *Arch Orthop Trauma Surg.* 1998; 117: 18-22. <http://bit.ly/2mkLk3c>
- Mont MA, Tomek IM, Hungerford DS. Core decompression for avascular necrosis of the distal femur: long term followup. *Clin Orthop Relat Res.* 1997; 334: 124-130. <http://bit.ly/2mhvSF9>
- Goodman SB, Hwang KL. Treatment of secondary osteonecrosis of the knee with local debridement and osteoprogenitor cell grafting. *J Arthroplasty.* 2015; 30: 1892-1896. <http://bit.ly/2mhvt5B>
- Bayne O, Langer F, Pritzker KP, Houpt J, Gross AE. Osteochondral allografts in the treatment of osteonecrosis of the knee. *Orthop Clin North Am.* 1985; 16: 727-740. <http://bit.ly/2lcH8Cz>
- Hangody L, Vasarhelyi G, Hangody LR, Sukosd Z, Tibay G, Bartha L, et al. Autologous osteochondral grafting--technique and long-term results. *Injury.* 2008; 39: S32-39. <http://bit.ly/2mKKAey>
- Chalmers BP, Mehrotra KG, Sierra RJ, Pagnano MW, Taunton MJ, Abdel MP. Reliable outcomes and survivorship of unicompartmental knee arthroplasty for isolated compartment osteonecrosis. *Bone Joint J.* 2018; 100: 450-454. <http://bit.ly/2mfVtE1>
- Yoon C, Chang MJ, Chang CB, Choi JH, Lee SA, Kang SB. Does unicompartmental knee arthroplasty have worse outcomes in spontaneous osteonecrosis of the knee than in medial compartment osteoarthritis? A systematic review and meta-analysis. *Arch Orthop Trauma Surg.* 2019; 139: 393-403. <http://bit.ly/2mKlPm>