Osteonecrosis of the Knee and Related Conditions

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Abstract

Osteonecrosis (ON) of the knee is a progressive disease that often leads to subchondral collapse and disabling arthritis. Recent studies have identified three distinct pathologic entities, all of which were previously described as knee ON: secondary ON, spontaneous ON of the knee, and postarthroscopic ON. Radiographic and clinical assessment is useful for differentiating these conditions, predicting disease progression, and distinguishing these conditions from other knee pathologies. The etiology, pathology, and pathogenesis of secondary ON of the knee are similar to those found at other sites (eg, hip, shoulder). Spontaneous ON is a disorder of unknown etiology. Postarthroscopic ON has been described as an infrequent but potentially destructive complication. Various treatment modalities (eg, core decompression, bone grafting, high tibial osteotomy, arthroplasty), have been used with varying degrees of success for each type of ON. Secondary ON frequently progresses to end-stage disease, and early surgical intervention is recommended. Initial management of spontaneous ON of the knee and postarthroscopic ON is typically nonsurgical, with observation for clinical or radiographic progression.

Ahlbäck et al[1] first described osteonecrosis (ON) of the knee in the 1960s. The condition was initially described as having a spontaneous presentation that typically involved the medial femoral condyle. Early reports noted a greater prevalence in women aged >60 years, often following minor trauma or increased activity. Later studies identified patients whose characteristics and symptoms did not match these initial descriptions, which led to the recognition of three unique entities: secondary ON, spontaneous ON of the knee, and postarthroscopic ON. However, our understanding of ON of the knee and its management is limited by persistent questions concerning etiology, a paucity of randomized trials, the use of disparate classification systems, and the inclusion in individual studies of patients with different underlying etiologies. Each type of knee OA has the potential to progress to end-stage arthritis. However, the etiology, associated risk factors, diagnostic evaluation, prognosis, and management approach may differ for each type. Table 1 lists key concepts related to ON of the knee.

Secondary Osteonecrosis

Epidemiology

The incidence of secondary ON of the knee has been estimated to be 10% that of hip ON.[2] Secondary

ON of the knee is more prevalent in certain patients, such as those who have undergone organ transplantation and those who receive high doses of corticosteroid. Persons with sickle cell disease have an annual incidence of approximately 3.6 cases per 100 patients.[3]

Anatomic Considerations

Secondary ON often involves both femoral condyles and presents with multiple lesions. The epiphysis, metaphysis, and diaphysis may be affected (Figure 1). The femur is affected in ≤90% of cases, and >80% of patients have bilateral disease and/or other joint involvement.[2,4]

Pathogenesis, Etiology, and Associated Risk Factors

The pathogenesis of secondary knee ON remains largely undefined. Table 2 lists proposed pathophysiologic etiologies. As with osteonecrotic hip disease, variable mechanisms may be implicated in the knee. Few studies have evaluated whether research on the hip is relevant to the knee. Uchio et al[5] assessed whether there was increased intraosseous pressure in the knee, as in the hip. They found the pressure in osteonecrotic medial condyles to be higher than that of the average of both condyles in patients with osteoarthritis (62.8 and 30 mm Hg, respectively).

The two risk factors most commonly associated with secondary knee ON are corticosteroid use and alcohol abuse (approximately 90%).[2] Although the pathogenesis may be similar, the specific mechanism remains unclear. Some authors have implicated elevated intraosseous pressure resulting from adipocyte hyperproliferation. Alternatively, fat emboli may occlude vessels in subchondral bone. In persons who abuse alcohol, these emboli likely originate from a fatty liver. There are anecdotal reports of ON occurring after the administration of low-dose corticosteroids or intra-articular injections; however, we do not believe sufficient evidence exists to suggest a cause-and-effect relationship. Lieberman et al[6] reported no association between corticosteroid use and ON

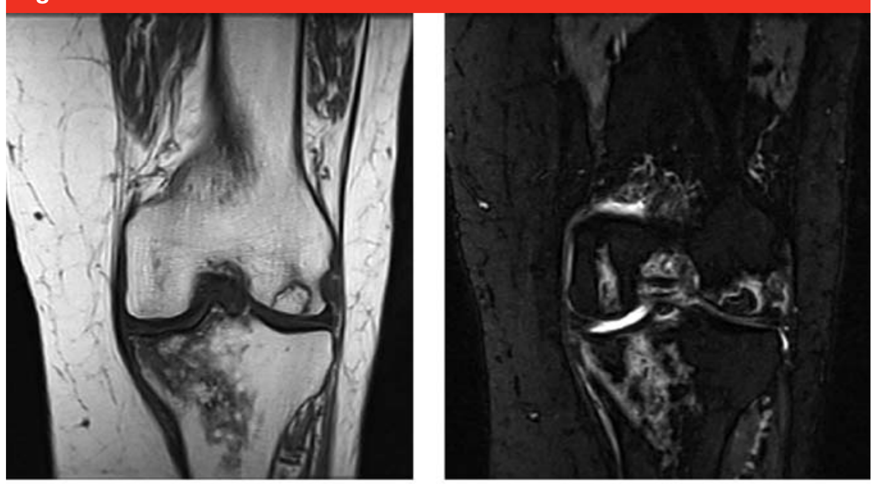
Table 1

Key Concepts in Knee Osteonecrosis

- The knee is the second most common site of ON.
- Secondary ON, spontaneous ON of the knee, and postarthroscopic ON are distinct pathologic entities, but they share some similarity in their presentation.
- Secondary ON has a multifactorial etiology and is characterized by loss of bone blood circulation.
- Controversy exists regarding whether spontaneous ON of the knee represents insufficiency fracture or part of the progression of osteoarthritis.
- Postarthroscopic ON is associated with subchondral collapse and may be associated with altered knee mechanics.
- MRI is the most sensitive and specific diagnostic tool for all three entities. Disease progression is monitored on standard radiographs.
- Nonsurgical management with analgesics and protected weight bearing is recommended for early-stage spontaneous ON of the knee and postarthroscopic ON, but it may not be appropriate for secondary ON.
- Patients in whom nonsurgical measures are unsuccessful may be treated with joint-preserving procedures. Joint arthroplasty is required for persons with subchondral bone collapse.

ON = osteonecrosis

Figure 1



A B

A, Coronal T1-weighted magnetic resonance image demonstrating characteristic findings of secondary osteonecrosis, such as multiple hypointense serpentine lesions surrounded by a well-demarcated hyperintense border. **B,** Coronal T2-weighted fat-suppressed magnetic resonance image demonstrating three types of lesion: early (medial femoral condyle), intermediate (tibial plateau), and late (lateral femoral condyle). The lesions progress from a relatively disorganized area of edema with hyperintense signal to a more mature lesion with a focus of necrotic tissue demonstrating hypointense fat signal surrounded by granulation tissue that appears as a rim of high intensity. (Copyright Sinai Hospital of Baltimore, Baltimore, MD.)

Table 2

Comparison of Clinical Presentation and Etiology in Knee Osteonecrosis

Characteristic	Secondary ON	Spontaneous ON of the Knee	Postarthroscopic ON
Age	Typically <45 years	≥50 years	Any
Sex	More likely in men than women	Female-to-male ratio of 3:1	No predilection
Bilaterality	>80%	<5%	Never
Other joint involvement	>90% (hip, shoulder, ankle)	No	No
Associated risk factors	Direct causes: trauma, caisson disease, chemotherapy, Gaucher disease, radiation. Indirect causes: alcohol abuse, coagulation abnormalities (thrombophilia, hypofibrinolysis), corticosteroid use, inflammatory bowel disease, organ transplant, systemic lupus erythematosus, smoking.	Idiopathic, chronic mechanical stress, or microtrauma	Meniscectomy, cartilage débridement, anterior cruciate ligament reconstruction, laser or radiofrequency-assisted surgery
Proposed pathogenic mechanisms	Direct cell injury Restriction or occlusion of blood supply Increased intraosseous pressure	Weight-bearing articular surface subjected to altered stresses as the result of subchondral fracture Vascular compromise to subchondral bone, resulting in osseous ischemia and subsequent edema Osteoarthritis variant	Abnormal loading leading to chondral injury, inflammation, edema, and intraosseous pressure Abnormal loading leading to microfracture and abnormal blood circulation Direct thermal or photoacoustic injury via laser or radiofrequency-assisted arthroscopy
Pathologic findings	Necrotic bone	Fibrotic bone, healing fracture, osteopenia, osteoarthritis, necrosis found only at the distal end of the fractured segment	Fibrotic bone and healing fracture. Necrotic bone after direct thermal or acoustic injury.

ON = osteonecrosis
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in persons who underwent cardiac transplantation. Only 6 of 204 patients developed ON despite high corticosteroid requirements. These authors concluded that ON was an idiosyncratic response that may be related to an underlying hypercoagulable state.

Conditions such as sickle cell disease, caisson disease, Gaucher disease, and myeloproliferative disorders are considered to be direct causes of knee ON. The pathomechanism in sickle cell and caisson disease is similar, with direct occlusion of blood vessels. Gaucher disease, leukemia, and myeloproliferative disorders are thought to increase intraosseous pressure by displacing marrow.

Genetic inheritance patterns associated with secondary ON have been studied extensively. Liu et al[7] found a collagen type II gene mutation with an autosomal dominant inheritance to be linked to ON in three families. Studies have shown that patients with inherited coagulation disorders are at high risk of secondary ON.[8-10] Patients who are diagnosed early may benefit from pharmacologic treatment.

Diagnosis

Clinical Assessment

Diagnosis is based on clinical suspicion and radiographic confirmation. A thorough patient history should identify associated risk factors. The physical examination often elicits nonspecific knee pain on extremes of range of motion. It is difficult to distinguish between the three knee disorders based on clinical presentation alone. Demographic factors may help differentiate the diseases (Table 2). Secondary ON is more common in men than women, except in persons with systemic lupus erythematosus. Patients with secondary ON are often aged <45 years and have one or more associated risk factors. Bilateral and multiple joint involvement is seen in >90% of cases.[2]

Several other diseases and conditions may present in a similar manner, such as meniscal or ligamentous injury. ON tends to progress to more advanced disease that requires surgi-

Table 3

Radiographic Assessment for Osteonecrosis of the Knee[a]

Imaging Type	Technical Considerations	Recommended Use
Standard radiography	AP, lateral, and PA bilateral weight-bearing views	Screen for other diseases in differential diagnoses: tumor, fracture, osteoarthritis. Diagnose late-stage disease. Assess disease progression with follow-up imaging.
MRI	Recommended: high-field scanner (≥1.5 Tesla) with extremity coil, T1-weighted and fluid-sensitive (fat-suppressed T2-weighted or STIR). Evaluate coronal, sagittal, and axial planes.	Diagnose early-stage disease. Confirm radiography in equivocal cases. Determine the extent of disease for surgical planning.
Technetium Tc-99m bone scanning	Inject 20–30 mCi technetium-99m methylene diphosphonate. Three phases: angiographic (2 min), tissue (2–4 min), and static (2–3 h). Measure uptake.	Detect early-stage disease in persons who cannot undergo MRI. Nonspecific modality for detecting late-stage disease.

STIR = short tau inversion recovery
[a] Similar for all three entities: secondary osteonecrosis, spontaneous osteonecrosis of the knee, and postarthroscopic osteonecrosis
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cal intervention, and early diagnosis is important.

Radiographic Assessment

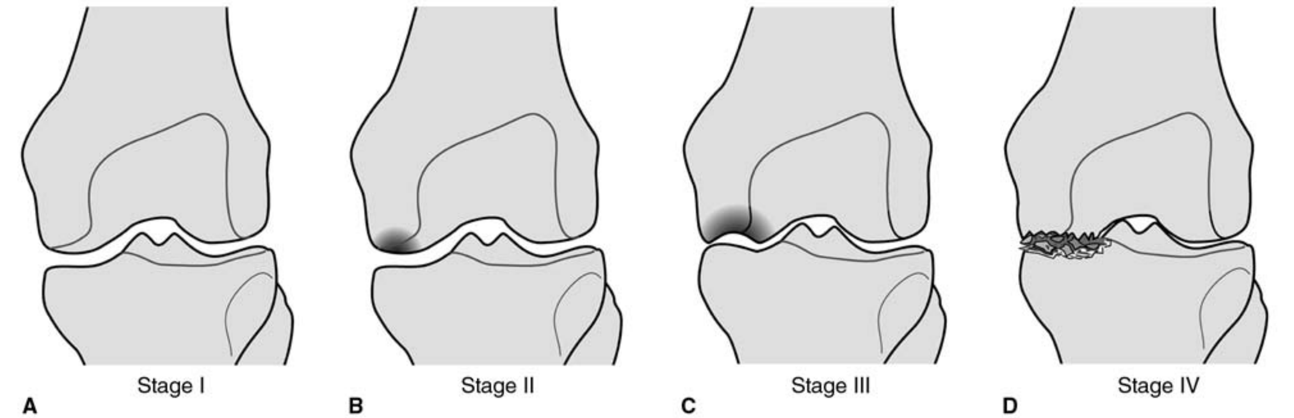
Standard radiography and MRI are recommended to evaluate the patient with suspected secondary ON (Table 3). AP and lateral radiographs can be used to diagnose advanced disease in persons with signs of impending subchondral fracture or collapse. Radiography is an inexpensive modality for staging and monitoring disease progression. Lesions can be detected earliest on MRI because of the ability to assess marrow viability and lesion distribution and to evaluate meniscal and chondral pathology. Many diseases demonstrate bone marrow edema on MRI. This nonspecific finding is associated with ischemia (eg, ON, bone marrow edema syndrome [ie, transient osteoporosis], osteochondritis dissecans), mechanical etiologies (eg, bone bruise, microfracture), and reactive processes (eg, osteoarthritis, postoperative bone marrow edema). MRI findings can be nonspecific; thus, disease-specific findings such as serpentine lesions with a well-demarcated border are necessary to make a diagnosis of ON.

Patients with secondary ON should be screened clinically for other joint involvement. The most frequently affected sites are the hip, shoulder, ankle, and contralateral knee. MRI of any other symptomatic joint may be appropriate as the initial screening in patients with secondary ON. Beer et al[11] performed MRI screening in five patients at high risk of ON following chemotherapy treatment. ON was detected in four patients. The knee and humeral head were the most commonly affected sites (nine and five, respectively). Evaluation of both hips may be appropriate regardless of the symptoms. One study demonstrated that 67% of patients with secondary ON had disease in one or both hips.[2] Hernigou et al[12] reported that 91% of patients with asymptomatic hip ON associated with sickle cell disease progressed to symptomatic disease at a mean follow-up of 14 years (range, 10 to 20 years). This finding reinforces the importance of close patient monitoring. Because of the high frequency of hip ON after chemotherapy (eg, acute lymphocytic leukemia) and organ transplantation, screening of the knees and hips has been recommended; however, further studies are needed to understand the potential benefits of screening.

Some authors prefer bone scintigraphy to detect early knee ON. However, Mont et al[13] reported that bone scans identified disease in only 37 of 58 patients (64%), whereas MRI detected all histopathologically confirmed lesions.

Several systems are used to stage knee ON radiographically. Most were reported in studies that assessed spontaneous ON of the knee; however, they can be used to assess secondary and postarthroscopic ON, as well. In all three of the four-stage systems, stage III is characterized by a crescent sign, representing collapsed subchondral bone[2,14,15] (Figure 2). Patients with stage III disease are unlikely to experience regression, and surgical intervention is typically required. Larger lesion size is predictive of disease progression. None of the four methods used to assess le-

Figure 2



Ficat staging of knee osteonecrosis, demonstrating the progression from precollapse lesions to late-stage disease and cortical bone collapse. **A,** Stage I, no radiographic evidence of knee osteonecrosis. The femoral condyles appear normal, with no sclerosis and maintained curvature. **B,** Stage II, signs of mottled sclerosis are evident, but the normal curvature of the bone remains intact. **C,** Stage III, the presence of a crescent sign is indicative of subchondral fracture, which defines this stage. **D,** Stage IV, collapse of the subchondral bone. (Copyright Sinai Hospital of Baltimore, Baltimore, MD.)

Table 4

Systems of Measuring Knee Osteonecrosis Lesion Size on Standard Radiographs

Study	Measurement	Classification[a]
Motohashi et al[16b]	Greatest width in AP and lateral views	Large (>10 mm)
Lotke et al[17]	The size ratio is measured by the greatest AP width divided by the width of the affected condyle	Large (size ratio >0.50)
Muheim and Bohne[18]	The surface area is calculated by multiplying the greatest AP width and the greatest lateral width	Large (>5 cm^2)
Mont et al[2c]	On AP and lateral views, the angle of the arc tangential to the two sides of the lesion and with the fulcrum at the physeal scar is measured. The sum of the two measures equals the combined necrotic angle.	Small (≤150°), intermediate (151° to 249°), large (≥250°)

[a] In general, larger lesions have a worse prognosis.
[b] Measuring system described by Ahlbäck et al.[1]
[c] Based on the measurements Kerboul et al[19] used for the hip.
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sion size has been validated (Table 4).

Management

Many treatment algorithms have been proposed for knee ON. However, they are primarily supported by limited retrospective reviews with relatively few patients. Prospective randomized studies and multicenter collaboration are needed. Several similar treatment options are available for the management of all three entities, with varying degrees of success (Tables 5 through 7).

Nonsurgical

Secondary ON progresses to advanced stages in approximately 80% of patients treated nonsurgically.[2] Thus, nonsurgical management is not recommended. Use of pharmacologic agents (eg, diphosphonates, anticoagulants) to manage secondary ON has been reported for ON of the hip.[41-43] However, no large randomized trials exist to confirm their efficacy, and further study is needed on the use of diphosphonates, iloprost, and anticoagulants. Iloprost is a prostacyclin analogue. This potent vasodilator may be useful in the management of ON by increasing blood flow to the affected region.

Joint-preserving Procedures

In early precollapse stages of secondary ON, joint-preserving surgical procedures such as core decompres-

Table 5

Results of Nonsurgical Management for Knee Osteonecrosis

Disease Entity[a]	Study	No. of Knees	Average Follow-up in Months (range)	Management	Outcomes
Secondary ON	Mont et al[22]	32	Minimum, 24	Protected weight bearing and analgesics	82% underwent TKA within 6 years
Spontaneous ON of the knee	Yates et al[20]	20[b]	4.8 (3–8)	Protected weight bearing	100% resolution on MRI
	Uchio et al[21]	18	52 (36–183)	Wedge insole	Hospital for Special Surgery knee score improved from 59 to 70 points. The necrotic area decreased from 2.3 to 1.3 cm^2.
	Lotke and Ecker[23]	36	42 (12–204)	Protected weight bearing and analgesics	89% clinically asymptomatic

ON = osteonecrosis, TKA = total knee arthroplasty
[a] No results on nonsurgical management of postarthroscopic ON have been reported in the current literature.
[b] MRI was unavailable for one patient at final follow-up.
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sion, arthroscopy, osteotomy, and bone grafting may be performed in an effort to avoid arthroplasty. Core decompression may be used in patients with ON but without subchondral collapse. It has been suggested that the therapeutic benefit of core decompression is the result of reduced marrow pressure and increased neovascularization, which allows formation of healthy bone. Large-diameter trephines were used in early studies. More recently, Marulanda et al[32] reported a small-diameter drilling technique (3.2-mm pin) based on a similar procedure that was previously reported for the hip. This percutaneous approach is performed under fluoroscopic guidance on an outpatient basis, and patients are restricted to weight bearing with crutches or a cane for the first month after surgery. This technique had a success rate of >90% (ie, Knee Society score ≥80 points) at 2- to 4-year follow-up (Table 6). Core decompression is unlikely to benefit the patient with joint collapse.

Bone graft has been used in persons with early-stage knee ON. Autologous and/or fresh-frozen allografts are incorporated to provide structural support to the subchondral bone and articular cartilage. We prefer to use a combination of cortical and cancellous allograft introduced through a 1- × 2-cm^2 extra-articular cortical window. Patients begin with protected weight bearing and are advanced to full weight bearing after 1 month. Although bone grafting has been used extensively in hip disease, few studies exist on its use in the knee. Two small reports encompassing three[24] and nine[25] knees have suggested that bone grafting may delay the need for joint arthroplasty in patients with precollapse disease (follow-up, 2 and 8 years, respectively) (Table 6). The authors of these two reports avoided the use of osteochondral grafts in patients with secondary ON for two reasons. First, there is the possibility of impaired healing potential of the underlying native bone. Second, the lesions usually involve multiple condyles, which do not lend themselves to a single osteochondral graft. In one study that reported on the use of fresh-frozen osteochondral allografts, ON affected predominantly one condyle.[34]

Evidence supporting these joint-preserving procedures is limited. No randomized trials are currently available, and the published studies tend to be small with relatively short follow-up.

Arthroplasty

Even with early treatment, many patients progress to advanced ON. Total knee arthroplasty (TKA) is recommended for persons with subchondral bone collapse and for those who have failed joint-preserving treatment. We do not recommend unicompartmental knee arthroplasty (UKA) because of the frequent involvement of multiple condyles. In addition, bone involvement tends to be extensive, which could compromise implant stability. However, Parratte et al[38] reported success with UKA in 10 patients with unicondylar secondary ON. Standard TKA surgical approaches and rehabilitation protocols can be used.

Excellent results have been reported with TKA to manage second-

Table 6

Results of Joint-preserving Procedures for Knee Osteonecrosis

Disease Entity	Study	No. of Knees	Average Follow-up in Months (range)	Management	Outcomes
Secondary ON	Lee and Goodman[24]	3	24	Cancellous bone allograft/cell therapy	Mean KSS, 97 points
	Marulanda et al[32]	61	37 (24–50)	Core decompression (small diameter)	92% had KSS ≥80
	Rijnen et al[25]	9	51 (29–93)	Impacted morcellized bone grafting	None progressed to arthroplasty. Mean KSS improved from 63 to 89 points.
	Fukui et al[33]	10	79 (31–159)	Osteoperiosteal autograft	90% had an improved KSS, with a mean improvement of 72 points on a 200-point scale
	Mont et al[22]	47	132 (48–192)	Core decompression	73% had KSS ≥80 points
	Flynn et al[34]	8	55 (24–109)	Fresh-frozen osteoarticular allograft	75% had occasional to no pain, unlimited walking without aids, and ≥95° of flexion, and were within 5° of full extension
	Meyers et al[35]	40	24–120	Fresh osteochondral allograft	31 (78%) were successful
Spontaneous ON of the knee	Deie et al[36]	12	25 (12–42)	Core decompression with artificial bone grafting	All had reduced pain and avoided TKA
	Duany et al[26]	7	40 (9–120)	Core decompression	87% avoided TKA. Mean KSS, 81 points.
		9	40 (9–120)	OAT	87% avoided TKA. Mean KSS, 81 points.
	Tanaka et al[37]	6	28 (23–45)	OAT	Complete resolution of pain
	Takeuchi et al[27]	30	40 (24–62)	High tibial osteotomy	Mean KSS improved from 51 to 93 points
	Akgun et al[28]	26	27 (12–78)	Arthroscopic microfracture treatment with concurrent partial meniscectomy	Clinical improvement in 96%. Radiographic progression of disease in 27%.
	Forst et al[29]	16	36 (3–60)	Core decompression	Pain resolved in 15 knees
	Miller et al[30]	5	31 (25–40)	Arthroscopic débridement	Four of five rated good based on HSS. Mean HSS improved from 52 to 82 points.
	Koshino[15]	37	62 (24–102)	High tibial osteotomy	Mean KSS: stage II, 95; stage III, 90; stage IV, 81
Postarthroscopic ON	Garino et al[31]	2	NA	Core decompression	Both patients required additional surgery (1 UKA, 1 patellectomy)

HSS = Hospital for Special Surgery knee score, KSS = Knee Society score, NA = not applicable, OAT = osteochondral autologous transplantation, ON = osteonecrosis, TKA = total knee arthroplasty, UKA = unicompartmental knee arthroplasty
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ary ON. Myers et al[4] reported a revision rate of 24% of TKAs performed prior to the year 1985 compared with a 3% revision rate for TKAs performed in 1985 and later. They concluded that modern cemented TKA designs and selective use of stems and augments provide outcomes that are similar to those reported for osteoarthritis. Other recent reports have shown similar findings (Table 7).

Table 7

Results of Unicompartmental Knee Arthroplasty and Total Knee Arthroplasty for Knee Osteonecrosis

Disease Entity	Study	No. of Knees	Average Follow-up in Months (range)	Management	Reported Outcomes
Secondary ON	Parratte et al[38a]	10	84 (36–192)	UKA	Mean KSS improved from 56 to 95 points
	Myers et al[4b]	150	96	TKA	74% good clinical results, 80% survivorship
Spontaneous ON of the knee	Servien et al[40]	33	60 (24–138)	UKA	Mean IKS score improved from 63 to 93 points. Two revisions to TKA.
	Parratte et al[38a]	21	84 (36–192)	UKA	Mean KSS improved from 56 to 95 points. 95% survival with one failure resulting from infection.
	Myers et al[4b]	64	60	UKA	90% good clinical results, 87% survivorship
		148	48	TKA	92% good clinical results, 97% survivorship
Postarthroscopic ON	Bonutti et al[39]	19	62 (24–133)	4 UKA, 15 TKA	95% had KSS of ≥80 points. Mean KSS, 92 points.

IKS = International Knee Society, KSS = Knee Society score, ON = osteonecrosis, TKA = total knee arthroplasty, UKA = unicompartmental knee arthroplasty

[a] Follow-up and outcomes are average for both spontaneous ON of the knee and secondary ON.

[b] Literature review of 20 cohorts treated for spontaneous ON of the knee or secondary ON. Good results were defined as no radiographic progressive lucencies or evidence of loosening, as well as a KSS of ≥80 points, Hospital for Special Surgery or global knee outcome score of ≥70 points, or author-reported good or excellent outcome (when no specific score was used).

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Spontaneous Osteonecrosis of the Knee

Epidemiology

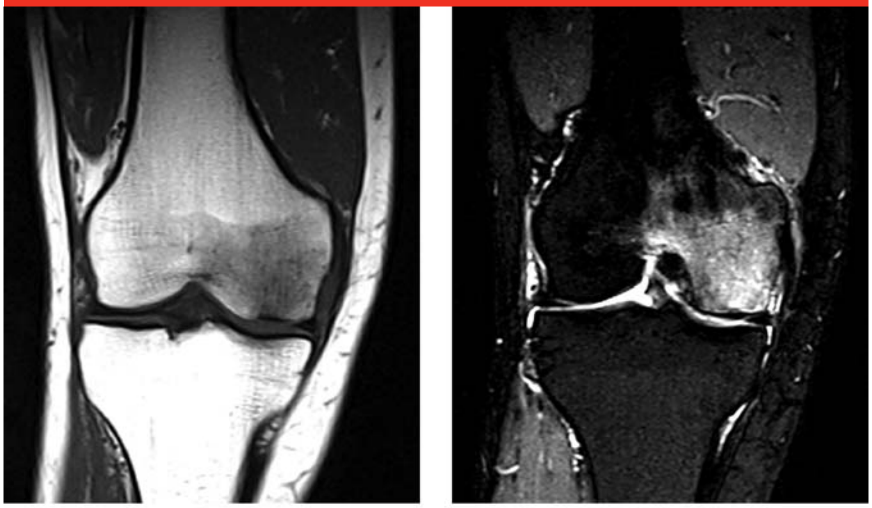
Few epidemiologic data exist on spontaneous ON of the knee, but it is considered to be more common than secondary ON. The prevalence of spontaneous ON of the knee may be underestimated because many patients who present with end-stage osteoarthritis may have had occult undiagnosed spontaneous ON of the knee. One study indicated a 3.4% incidence of spontaneous ON of the knee in persons aged >50 years who presented with symptoms in the medial meniscus and an incidence ≤9.4% in persons aged >65 years.[44]

Anatomic Considerations

The medial femoral condylar epiphysis is the most frequent site of spontaneous ON of the knee (Figure 3). On MRI, spontaneous ON of the knee typically appears as a focal, low-signal finding with linear features in the subarticular bone of the epiphysis. The medial tibial plateau is affected in approximately 2% of cases.[23] Spontaneous ON of the knee rarely occurs in the patella or the lateral femoral condyle. Most cases are unilateral. However, a recent case report demonstrated a patient with bicondylar spontaneous ON of the knee.[45] In such instances, an understanding of the underlying risk factors and radiographic findings associated with secondary ON is helpful in diagnosis.

The propensity for spontaneous ON of the knee to affect the medial femoral condyle may be explained by local differences in blood supply to anatomic regions of the knee. Reddy and Frederick[46] injected cadaver specimens with India ink to compare the extra- and intraosseous arterial blood supplies to the lateral and medial femoral condyles. With regard to the extraosseous blood supply, the superior and inferior lateral genicular arteries were found to supply the lateral femoral condyle. The superior medial genicular artery supplies the medial femoral condyle. The intraosseous blood supply to the lateral condyle consisted of an arcade of vessels with no obvious watershed region of limited vascularity. In con-

Figure 3



A B

A, Coronal T1-weighted magnetic resonance image in a patient with spontaneous ON of the knee demonstrating a lesion surrounded by diffuse bone marrow edema that appears hypointense. **B,** Coronal T2-weighted fat-suppressed magnetic resonance image demonstrating an area of low signal intensity surrounded by high signal intensity caused by edema. (Copyright Sinai Hospital of Baltimore, Baltimore, MD.)

trast, the intraosseous blood supply to the medial condyle consisted of a single nutrient vessel with an apparent watershed area. Based on these differences, Reddy and Frederick[46] hypothesized a greater propensity for the development of ON in the medial femoral condyle. They also noted that the standard femoral tunnel used during posterior cruciate ligament reconstruction lies in close proximity to the extraosseous vessels, which could explain the occurrence of ON following that procedure. A more recent study reported the development of ON following anterior cruciate ligament surgery.[47] Those authors postulated that femoral tunnel drilling may have contributed to the development of disease.

Pathogenesis, Etiology, and Associated Risk Factors

Recent studies have attempted to elucidate the underlying pathogenesis of spontaneous ON of the knee. Early theories suggested a vascular origin, with compromised microcirculation to the subchondral bone resulting in edema, increased intraosseous pressure, and, ultimately, ischemia and necrosis. However, recent pathologic studies have not revealed evidence of necrotic bone. Radiologic and pathologic evidence suggest that, in some cases, spontaneous ON of the knee may be the result of a subchondral insufficiency fracture. As many as 80% of patients may present with a meniscal root injury, as well.[48] Some authors have suggested a traumatic origin because spontaneous ON is commonly seen in elderly women with osteopenic bone, which is susceptible to microfracture. The authors of one histologic study on whether the disease follows insufficiency fracture reported that many patients had evidence of subchondral fracture, with a reparative reaction consisting of osteoid and immature bone; however, they noted no evidence of necrosis.[49]

These findings suggest that “spontaneous ON of the knee” is a misnomer and that it is, in fact, a disease that should be defined as an unstable fracture initially, which then becomes true bone death of the displaced fracture fragment in later stages. These findings are supported by Ramnath and Kattapuram,[50] who showed that in 52 subchondral lesions identified as spontaneous ON of the knee, patients with a subacute presentation had insufficiency fracture, and patients with chronic disease had osteoarthritis.

In contrast with the insufficiency fracture theory, a histologic study of 22 specimens by Mears et al[51] noted no evidence of appositional bone repair to suggest an occult fracture. Although there was no evidence of dead bone or ON, 14 specimens (64%) showed marked osteopenia, and 15 (68%) showed evidence of osteoarthritis.

Diagnosis

Patients with spontaneous ON of the knee typically present with well-defined pain at the medial aspect of the distal femur. This may mimic the pain experienced following tear of the medial meniscus. The pain is often worse at night and on weight bearing. Women are approximately three times more likely than men to have this pain; most patients present in their late fifties or later[49] (Table 2).

Recommended imaging modalities are similar to those for secondary ON. Table 2 lists findings that help distinguish these two entities. Some authors prefer bone scintigraphy for detecting early spontaneous ON of the knee. Soucacos et al[14] noted that bone scans are sensitive in the incipient stage and that MRI may be inconclusive. However, transient bone marrow edema changes cannot be distinguished from ON based on bone scans alone. Lecouvet et al[52] described MRI characteristics that distinguish edema from spontaneous ON of the knee. Indications of the latter include the presence of a subchondral area of low signal intensity on T2-weighted magnetic resonance images, a focal epiphyseal contour depression, and lines of low signal intensity located deep to the affected condyle.

Nonsurgical Management

Initial management of precollapse spontaneous ON of the knee should include protected weight bearing, analgesics as required, and nonsteroidal anti-inflammatory drugs if tolerated. This approach is believed to reduce stress on the bone, which may halt or reverse disease progression. Early-stage spontaneous ON of the knee responds favorably to nonsurgical management, with resolution of symptoms in ≥89% of patients with precollapse disease and no changes on plain radiographs[17,20,21] (Table 5). Surgery should be considered for patients who do not improve clinically and/or radiographically (ie, regression of the lesion size on MRI) by 3 months following symptom onset. The favorable natural history of small and midsized lesions associated with spontaneous ON of the knee suggests that surgical intervention should be considered only after nonsurgical management fails.

Surgical Management

Joint-preserving Procedures

Core decompression may be used in patients who remain symptomatic despite protected weight bearing; however, outcomes data are limited. Forst et al[29] reported clinical improvement in 15 of 16 patients with early-stage spontaneous ON of the knee, defined as a lack of previous severe knee pain immediately following surgery as well as an improvement in mean Knee Society scores from 74 (SD, 38) points preoperatively to 187 points (SD, 52) at a mean follow-up of 35 months (range, 3 to 60 months) (Table 6).

Arthroscopy for knee ON remains undefined, but it does allow additional assessment of ON lesions, and coexisting meniscal tears or chondral lesions can be addressed at the same time. Typically, rehabilitation with protected weight bearing is recommended for the first month. Miller et al[30] suggested performing arthroscopic débridement for initial management of spontaneous ON of the knee. However, lesion size is ultimately more prognostic. Akgun et al[28] performed arthroscopic microfracture repair in 26 patients with spontaneous ON of the knee who either failed a minimum of 4 months of protected weight bearing or developed mechanical symptoms. Clinical improvement was seen in 96% of patients at a mean follow-up of 27 months (range, 12 to 78 months) (Table 6).

Multiple centers have reported on bone grafting for the management of spontaneous ON of the knee[26,36] (Table 6). Deie et al[36] treated 12 patients with core decompression and artificial bone graft with an interconnected porous structure. All patients reported a reduction in knee pain and showed no radiographic progression at a mean follow-up of 24.6 months (range, 12 to 42). High tibial osteotomy is rarely used to manage medial femoral condylar lesions and varus knee deformity in persons with spontaneous ON of the knee[15,27] (Table 6).

Patients who progress to subchondral collapse may benefit from osteochondral autologous transplantation or mosaicplasty. Localized lesions are filled using autologous osteochondral tissue harvested from uninvolved articular surfaces that undergo less weight bearing. After 4 weeks of rehabilitation and protected weight bearing, patients are allowed to progress to full weight bearing. Midterm results for repairing defects of the weight-bearing surfaces have been favorable. Duany et al[26] reported a successful clinical outcome in eight of nine patients who underwent osteochondral autologous transplantation at a mean follow-up of 42 months. The mean Knee Society score was 85 points (range, 60 to 100). These procedures are typically reserved for young patients; however, this technique has been used in patients as old as 76 years.[26]

The evidence for the use of joint-preserving techniques is limited. Most studies are limited by an uncontrolled retrospective design and a small number of patients. High tibial osteotomy is the only procedure about which results have been reported for ≥30 patients.[15,27]

Arthroplasty

UKA may be appropriate for some patients with spontaneous ON of the knee and end-stage osteoarthritis because the disease typically affects a single condyle.[4,38] Persons with osteoarthritis in more than one compartment should undergo TKA.[4]

Postarthroscopic Osteonecrosis

Epidemiology and Anatomic Considerations

Relatively few cases of postarthroscopy ON are reported each year, considering the large number of meniscectomy procedures performed. However, one study reported this complication in 2 of 50 patients (4%).[53]

Most reported cases of postarthroscopic ON occur at the medial femoral condyle. The lateral femoral condyle is the second most frequently affected site. In rare cases, the lateral tibial plateau, medial tibial plateau, or patella is affected.

Figure 4

A **B**

AP radiograph (**A**) and coronal T2-weighted magnetic resonance image (**B**) of the right knee in a patient who developed postarthroscopic osteonecrosis of the medial femoral condyle (arrowheads) following meniscectomy. This patient eventually underwent total knee arthroplasty. (Copyright Sinai Hospital of Baltimore, Baltimore, MD.)

Pathogenesis, Etiology, and Associated Risk Factors

The etiology of postarthroscopic ON likely varies based on whether mechanical surgical instruments or laser probes were used. Most early studies evaluated cases in which disease developed following arthroscopy performed with mechanical surgical instruments only, and it was suggested that occult damage was caused to the cartilage and meniscus.[54] Such damage could lead to altered biomechanics and subsequent bone contact pressure sufficient to cause pathologic fracture of subchondral bone and synovial fluid leakage. Accumulation of fluid and subchondral edema may be exacerbated by increased absorption of arthroscopy fluids into the pathologic cartilage.[54]

Another hypothesis is that “postarthroscopic ON” is actually subchondral fracture. MacDessi et al[55] assessed seven patients (eight knees) with histologic evidence of subchondral fracture characterized by disruption of the trabecular architecture but without ON. These findings were similar to pathology seen in persons with spontaneous ON of the knee.[49]

ON following radiofrequency or laser-assisted arthroscopic surgery was initially believed to be related to a different pathogenesis. Currently, no consensus exists as to its pathogenesis. Some authors have suggested that thermal energy may directly damage bone tissue or that photoacoustic shock may play a role in ON via the formation of a wave generated from expanding gases produced by the rapid vaporization of cellular contents and intracellular water.[56]

Diagnosis

Postarthroscopic ON has no age or sex bias, and the lesion is typically localized to the compartment in which the surgery was performed. In one study, patients presented with sudden-onset pain approximately 24 weeks following arthroscopy (range, 4 to 92 weeks).[39] Pain early in the recovery period may be mistaken as normal postoperative healing.

MRI as well as AP and lateral radiographs are recommended in patients with suspected postarthroscopic ON (Figure 4). The bone marrow edema is located adjacent to the meniscectomized compartment. On T1-weighted magnetic resonance images, these lesions have an appearance similar to that of spontaneous ON of the knee, with linear foci of low signal surrounded by diffuse marrow edema in the affected area. Patients should have no evidence of bone marrow edema preoperatively.

Management

Protected weight bearing, analgesics, and nonsteroidal anti-inflammatory drugs may be beneficial. The best outcomes are achieved in patients with small early-stage precollapse lesions without degenerative articular surface changes.

Few reports exist of the use of joint-preserving procedures to manage postarthroscopic ON[31,57] (Table 6). Joint-preserving interventions may be a reasonable approach in persons who have failed nonsurgical treatment.

TKA and UKA are recommended for patients with end-stage osteoarthritis. Bonutti et al[39] performed minimally invasive knee arthroplasty on 19 patients with postarthroscopic ON. They reported good to excellent clinical results in 95% at a mean follow-up of 62 months (range, 24 to 133 months).

Summary

In the past several years, three distinct knee ON entities have been identified: secondary ON, spontaneous ON of the knee, and postarthroscopic ON. Although the pathogenesis, associated risk factors, and diagnosis of these entities have been elucidated, none of these conditions is fully understood. MRI is generally accepted as the most sensitive and specific diagnostic tool. Management is based on the stage of disease. Randomized prospective studies are needed to establish treatment recommendations. Based on recent literature, precollapse secondary ON should be managed with joint-preserving surgical procedures. In contrast, early spontaneous ON of the knee and postarthroscopic ON should initially be managed nonsurgically. Joint-preserving interventions may be used in patients with recalcitrant disease but without joint collapse. In all three entities, TKA and UKA are the standard management strategies for end-stage disease that has progressed to osteoarthritis.

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References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 13 is a level I study. References 5, 6, and 21 are level II studies. References 2, 3, and 15 are level III studies. References 4, 7, 11, 12, 16-18, 20, 24-31, 34, 36, 38, 39, 44-48, 50-55, and 57 are level IV studies. References 14, 49, and 56 are level V expert opinion.

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