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Original Article

Knee Arthroplasty After Subchondroplasty: Early Results, Complications, and Technical Challenges

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ABSTRACT

Background: Calcium phosphate bone substitutes (CPBS) are commonly used to augment and repair bone voids and defects after fractures around the knee joint. The purpose of this study was to determine whether prior arthroscopic application of a CPBS, for repair of magnetic resonance imaging–identified subchondral fractures associated with osteoarthritis (procedure referred to as subchondroplasty) adversely affected the performance and/or outcome of subsequent knee arthroplasty.

Methods: Twenty-two patients who had arthroscopic repair of a periarticular fracture combined with use of a CPBS who later had knee arthroplasty were identified. Average follow-up for study patients was 23.5 months (range 12-52 months). These patients were matched demographically and for follow-up duration in a 2:1 ratio to a group of control subjects undergoing arthroplasty who had not undergone prior surgery.

Results: Technical challenges related to surgical performance, clinical outcomes, and complications were determined for both the groups. At most recent follow-up, study patients had an average Oxford score of 40.6 (range, 25-48) compared with control subjects with an average score of 40.1 (range, 12-48). There was no difference in complications or surgical complexity between groups, and only standard primary components were used.

Conclusion: The results of our study suggest that prior arthroscopic repair combined with CPBS of periarticular fractures around the knee does not compromise the early outcomes and surgical performance or increase complications related to subsequent arthroplasty. However, longer follow-up of these patients is warranted to confirm that implant durability remains uncompromised.

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Unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA) both predictably relieve pain and improve function in patients with advanced knee osteoarthritis (OA) [1-3]. However, it has been reported that the complexity of arthroplasty surgery is increased in patients who have had previous knee surgery [4-6]. In addition, there may be more complications and poorer arthroplasty outcomes in this particular patient population. Several authors have reported that TKA after high tibial osteotomy (HTO) yields satisfactory results [7-15]. Nonetheless, when compared with a control population that did not previously undergo HTO, functional recovery was less satisfactory after TKA [7,8]. In addition, the technical challenges of performing TKA after HTO have been well described [8,10,16,17]. Some authors have also noted that complications after TKA in patients with a previous HTO are more frequent [18-20]. Likewise, TKA after open reduction and internal fixation (ORIF) of fractures around the knee joint can be difficult [4,18]. Prior ORIF of the patella, distal femur, or proximal tibia have all been reported to increase the complexity of performing TKA [19-22].

Arthroscopically assisted repair of distal femur and proximal tibia fractures has been reported to be efficacious [23,24]. Calcium phosphate bone substitutes (CPBS) are often used in conjunction with arthroscopy to serve as bone void fillers and provide mechanical support of the articular surface [25,26]. Despite surgical treatment, some patients will experience clinical deterioration after undergoing periarticular fracture repair and require arthroplasty [27-29]. The purpose of this investigation was to determine

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whether prior arthroscopically assisted fracture repair using a CPBS: (1) is associated with inferior outcomes after subsequent TKA or UKA, (2) leads to increased complications after arthroplasty, and (3) increases the complexity of arthroplasty.

Methods

Twenty-two consecutive patients who had a total of 23 prior arthroscopically assisted proximal tibia and/or distal femur fracture repair procedures with associated use of a CPBS (1 patient had bilateral repairs), a procedure referred to as subchondroplasty, were studied. The indication for subchondroplasty was painful OA, refractory to nonoperative care, in patients with a magnetic resonance imaging–identified bone marrow lesion. Subsequently, these patients underwent either UKA (n = 7) or TKA (n = 16). The CPBS was percutaneously placed, and no patient had additional supplemental fracture fixation. For the study patients, a CPBS had been implanted in the medial femoral condyle (n = 1), lateral tibial plateau (n = 2), and medial tibial plateau (n = 4). Fourteen patients had a CPBS implanted in both the medial femoral condyle and medial tibial plateau, and 2 patients had CPBS placed in both the lateral femoral condyle and lateral tibial plateau. All patients met the traditional indications for arthroplasty (ie, significant, progressive symptoms refractory to standard nonoperative interventions) and had radiographically advanced knee OA (Kellgren–Lawrence Grade III or IV). A single surgeon performed all the arthroplasty procedures using a medial parapatellar approach. Preoperatively, either UKA or TKA using standard implants and instruments was planned. Due to the possibility of unexpected findings at surgery, implants were available that could provide additional fixation (eg, stemmed components, augments) if needed. In addition, if UKA was planned, TKA implants were also available. Because most CPBS products crystallize *in vivo*, a burr was also available for removal of the bone substitute if bone preparation using standard instruments was impeded. If UKA was planned preoperatively, it was also noted if the prior procedure adversely influenced the need for unexpected TKA. If TKA was performed, it was noted whether enhanced implants with stems or augments were needed to achieve adequate fixation. Intraoperative complications, including fracture, patellar tendon avulsion, neurovascular injury, and so forth were also documented if they occurred.

At the time of surgery, the subchondral bone in the region of the CPBS was carefully inspected and palpated to determine structural integrity and incorporation of the CPBS material. All retrieved bones were sent for routine pathology analysis. This analysis included gross inspection followed by decalcification and histologic evaluation. Typical bone resections were performed using battery-powered saws.

All subjects had postoperative follow-up at an average of 23.5 months (range, 12-52 months). Standard radiographs (anteroposterior, lateral, and sunrise views) were obtained at the latest follow-up visit and evaluated for component alignment, radiolucencies, progressive radiolucencies, bone remodeling, and component migration and/or subsidence. Surgical outcomes were determined by obtaining an Oxford Knee Score for all patients. Postoperative complications, including infection, reoperation for any reason, venous thromboembolic events, stiffness, and hemarthrosis were documented. In addition, operative times (incision to completing wound closure) and perioperative calculated blood loss were determined for both the groups.

A control group of patients who had UKA or TKA without prior knee surgery was matched to the group of study patients 2:1 for disease severity (using radiographic criteria), length of follow-up (average 27.5 months [range 12-42 months]), planned intervention (TKA or UKA), and demographics (gender, age, and body mass index).

Technical challenges related to arthroplasty performance, clinical outcomes, and complications were determined for both the study and control groups and statistically compared. Statistical analyses were performed using the statistical software language R (R Foundation for Statistical Computing, Vienna Austria). Fisher's exact test was used for categorical variables. Mann-Whitney tests were used for continuous variables. To account for patient matching, statistical analysis was performed using mixed-effects linear regression model for surgical outcomes such as blood loss and operative time. Appropriate mathematic transformations were used to satisfy the assumptions of linear regression. Significance was set at $P < .05$. Data ranges and P values were determined for all measured parameters and are included in the Tables 1 and 2.

Results

All patients in both the study and control groups underwent either UKA or TKA without intraoperative complications. Demographic data are summarized in Table 1. There were no significant differences between the study and control groups. Preoperatively, UKA was planned and performed for 8 study patients. No patient with planned UKA in the study group required intraoperative conversion to TKA. Cruciate retaining implants were used for all study and control patients receiving TKA. No stems, augments, or other options (eg, bone graft) to improve implant fixation or repair bone defects were needed in either group of patients.

Clinical data are summarized in Table 2. There was no significant difference in operative time or calculated total blood loss between the experimental and the control groups. Arthroplasty outcome, as determined by Oxford score, was not significantly different for study and control subjects ($P = .66$). The average Oxford score for subjects at latest follow-up was 40.6 (range, 25-48). The average Oxford score for controls was 40.1 (range, 12-48). Follow-up for the control group averaged 27.2 months (range, 12-42 months) and 23.5 months (range, 12-52; $P = .3$) for study patients.

During arthroplasty, CPBS-implanted bone regions were carefully inspected visually and by manual probing. The CPBS consistently appeared to be well incorporated. In addition, the structural integrity of the CPBS was not observationally compromised and appeared consistent with the sclerotic subchondral bone often encountered during arthroplasty (Fig. 1). Due to these findings, standard implants, without fixation enhancement or the need to replace bone defects, were used for all study patients.

Preparation of the tibia for the implant keel in all study patients undergoing TKA was performed without a burr, and only standard surgical instruments were needed. The tibial implant keel did not enter the bone substitute region in any patient. In general, the subchondral fractures in these study patients were peripherally located and juxtaposed to cortical bone. Therefore, the CPBS was also implanted in this region, and the tibial implant keel did not

Table 1
Demographic Data.

Parameter	Experimental	Control	*P* Value
Number of arthroplasties, n	23	46	
Age, mean (range), y	62 (51-80)	63 (51-80)	.74
Gender	14 females 9 males	26 females 20 males	1.0
BMI, mean (range)	31.1 (22.2-42.9)	30.7 (20.5-44.7)	.74
Charleston comorbidity index, mean (range)	2.1 (1-5)	2.3 (1-7)	.81

BMI, body mass index.

Table 2
Clinical Data for Experimental and Control Groups.

Parameter	Experimental Group (n = 23)	Control Group (n = 46)	*P* Value
Total calculated blood loss, mL, average (range)	1119 (646-2198)	1294 (618-2531)	.23
Operating room time (min), average (range)	57.7 (35-100)	57.0 (36-96)	.76
Length of follow-up, mo, average (range)	23.5 (12-52)	27.1 (12-42)	.03
CPBS integration n (%) and adequate structural integrity	23 (100)	0	N/A
Need for specialized surgical instruments, n	0	0	1.0
Stemmed implants and/or augments used	0	0	1.0
Revision and/or additional surgery	1	3	1.0
Average Oxford score	40.6 (25-48)	40.1 (12-48)	.66

CPBS, calcium phosphate bone substitutes.

extend close enough to the periphery of the tibia to cross through the CPBS. Due to the hardness of the bone substitute, however, had it been necessary for the tibial keel to cross this region, a burr would have been used before keel broaching to avoid potential intraoperative fracture secondary to the presence of the CPBS. The average time interval from performance of fracture repair to arthroplasty was 12 months (range, 4-31 months).

At latest arthroplasty follow-up, there were no radiographically loose implants in any patient in the study or control cohorts (Table 2). Prearthroplasty (postsubchondroplasty) and post-arthroplasty radiographs for 1 patient are represented in Figure 2. In the study group, 1 patient required wound revision for delayed healing. In the control group, 3 patients required additional surgery. Two patients needed revision TKA, 1 for infection and 1 for patella instability. A third control patient had arthroscopic debridement for stiffness and peripatellar crepitus. No patient in the study group needed postoperative manipulation under anesthesia. Four control patients required a manipulation under anesthesia.

Discussion

Numerous authors have reported satisfactory results and durable outcomes after both UKA and TKA using a variety of methods and implants [7-15]. A history of major knee surgery creates increased challenges for the performance of subsequent arthroplasty. Yoshino et al [9] reported that the complexity of TKA is greatly increased in patients who have had a prior HTO. In addition to increased difficulty of exposure, patients with a previous HTO often require more constrained implants, and revision knee arthroplasty components may be needed [8,10,16,17].

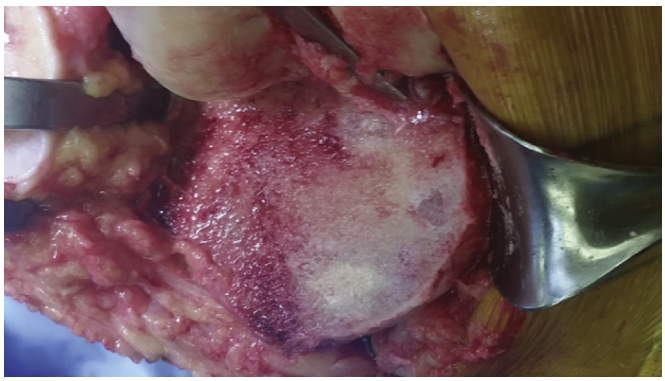

Fig. 1. Resected surface of tibia with demonstration of CPBS integration and structural integrity.

Although the clinical results of TKA after HTO are satisfactory, they have been reported to be diminished when compared with a group of patients not having previous major knee surgery [7,8]. Mont et al and Walther et al noted that patients who have had an HTO before TKA reported higher pain and lower function scores after the arthroplasty [26,30].

Likewise, a history of periarticular ORIF before TKA can be problematic [4,18]. It has been found that ORIF of the patella, distal femur, or proximal tibia creates unique challenges when performing later TKA [4,6-22,30,31]. A previous ORIF has also been reported to diminish clinical results and increase the incidence of complications after TKA [19-22]. Incisions related to major knee surgery can lead to significant challenges if subsequent TKA is needed, particularly when the old incision cannot be used to perform the index arthroplasty [32].

The success of TKA, combined with the knowledge that prior procedures can adversely affect the later performance and results of TKA, demands thorough evaluation of any surgical intervention used in a patient who may later need joint arthroplasty. Although arthroscopically assisted fracture repair combined with use of a percutaneously implanted CPBS is generally considered minimally invasive, the potential for this intervention to adversely affect later arthroplasty must be considered. To our knowledge, our study is the first report related to the performance and results of UKA or TKA in patients who previously had arthroscopically assisted fracture repair combined with use of a CPBS. Because this fracture repair methodology combines percutaneous implantation of a CPBS with arthroscopy, we noted that prior incisions did not create difficulties with the surgical exposure during subsequent performance of arthroplasty. Bone quality is an important consideration when performing UKA or TKA, and implantation of a CPBS has the potential to adversely affect this parameter and likewise the performance and results of later arthroplasty.

One limitation of our investigation is that all patients had previously been treated using a single CPBS (Accufill; Zimmer Orthopaedics, Warsaw, IN). Therefore, our findings may not be applicable if other CPBS products are used for fracture repair. The properties of this particular CPBS have been studied in both *in vitro* and *in vivo* animal models [33]. Clinical trials where this material for fracture repair was used have also been performed [34]. These investigations have reported that this CPBS has a satisfactory safety profile and potent osteoconductive capacity [35-37]. The procedure itself may also stimulate some degree of osteoinduction [38]. Animal studies have demonstrated rapid material remodeling with conversion to cancellous bone consistent with normal subchondral bone [39]. Biomechanically, this CPBS has been reported to have a 10- to 15-MP modulus of elasticity, similar to normal cancellous bone [40-42].

Consistent with the aforementioned noted reports, we found that the investigated CPBS consistently appeared well incorporated and structurally sound. Retrieved bone specimens were sent to pathology and visually inspected. Bone was then decalcified and microscopically studied. Thus, absolute confirmation of incorporation and degree of remodeling was not possible. In our series, the performance of prior fracture repair did not complicate the later performance of UKA or TKA. In all cases, the implants that were preoperatively planned for use were indeed used. Implants with extended stems, augments, or combined with bone grafts were not needed.

Radiographically, our data suggest that prior arthroscopic fracture repair combined with a CPBS did not have an adverse effect on implant stability. Nonetheless, a weakness of this study is that

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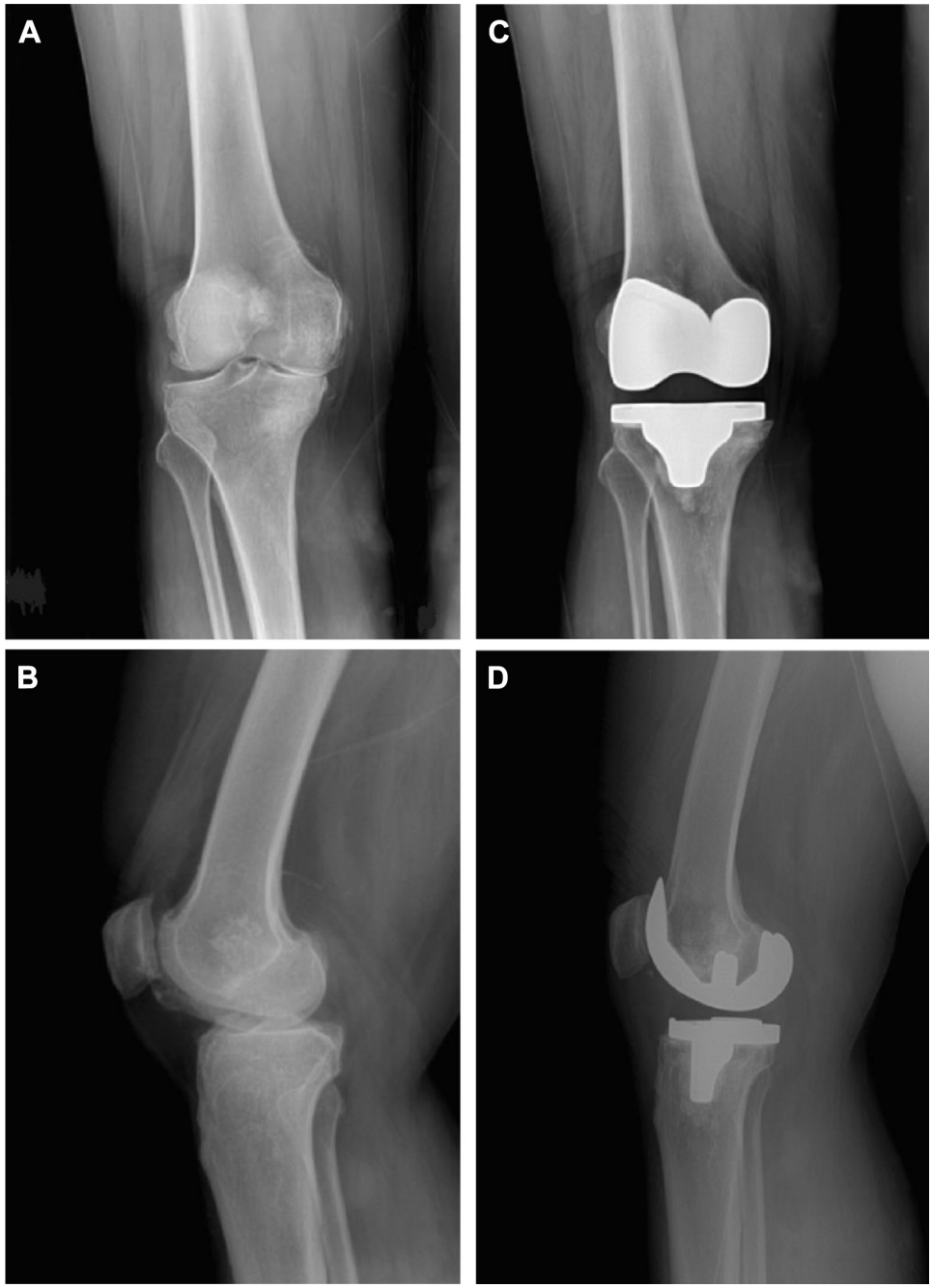

Fig. 2. (A, B) Anteroposterior and lateral radiographs after subchondroplasty. (C, D) Anteroposterior and lateral radiographs of the same patient after total knee arthroplasty.

follow-up time is relatively short, and continuous monitoring of study patients is warranted. Of note, a statistically significant difference in follow-up time was noted; however, we do not feel that this influenced the ultimate outcome of the study. Clinically typical results and outcomes after both UKA and TKA were noted for study patients.

Furthermore, TKA or UKA was performed with standard surgical instruments and without unexpected complications. Nonetheless, based on the apparent structural rigidity of this CPBS, it seems prudent to have a burr available during broaching for the tibial keel should this keel cross the boundary into the bone substitute region. Broaching hard sclerotic bone can lead to intraoperative fracture.

Despite lack of long-term data, we believe this investigation has substantial merit. Arthroscopically assisted fracture repair with or without combined use of a CPBS is a commonly performed intervention [23,24]. As with any procedure used in a patient who may need later arthroplasty, careful surveillance for unexpected or adverse consequences of the prior intervention is critical. The significance of these events, if found, must be quantitated to determine the true efficacy of prearthroplasty intervention.

In this study, the time from fracture treatment to conversion arthroplasty was relatively short for some patients. However, even when early conversion occurred, based on careful intraoperative inspection and probing, the CPBS-native bone construct appeared structurally sound and capable of adequately supporting the arthroplasty implant. Although no study patient developed radiographic loosening, it is important to recognize that eventual CPBS

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resorption, without remodeling to bone is a possibility and if this were to occur, it could compromise arthroplasty durability.

In summary, we did not find that prior performance of arthroscopically assisted fracture repair combined with use of a CPBS increased the difficulty or complexity of subsequent UKA or TKA. It is important to note that our patients had expected outcomes without an increased risk of complications after arthroplasty. However, it is also important to recognize that these patients had arthroscopic repair with percutaneous incisions and without use of internal fixation (other than the injected CPBS). Based on previous literature, our results should not be considered generalizable to patients who have had a previous traditional ORIF before knee arthroplasty. Longer follow-up of these patients is warranted to ensure implant durability, and subjects in this study will continue to be monitored.

References

1. Insall JN, Binazzi R, Soudry M, et al. Total knee arthroplasty. Clin Orthop Relat Res 1985;192(1):13.
2. Borus T, Thornhill T. Unicompartmental knee arthroplasty. J Am Acad Orthop Surg 2008;16(1):9.
3. Foran JR, Mont MA, Etienne G, et al. The outcome of total knee arthroplasty in obese patients. J Bone Joint Surg Am 2004;86-A(8):1609.
4. Lizaur-Utrilla A, Collados-Maestre I, Miralles-Muñoz FA, et al. Total knee arthroplasty for osteoarthritis secondary to fracture of the tibial plateau. A prospective matched cohort study. J Arthroplasty 2015;30:1328.
5. Klit J. Results of total joint arthroplasty and joint preserving surgery in younger patients evaluated by alternative outcome measures. Dan Med J 2014;61(4):B4836.
6. Bastos Filho R, Magnussen RA, Duthon V, et al. Total knee arthroplasty after high tibial osteotomy: a comparison of opening and closing wedge osteotomy. Int Orthop 2013;37(3):427.
7. Haslam P, Armstrong M, Geutjens G, et al. Total knee arthroplasty after failed high tibial osteotomy long-term follow-up of matched groups. J Arthroplasty 2007;22(2):245.
8. Haddad FS, Bentley G. Total knee arthroplasty after high tibial osteotomy: a medium-term review. J Arthroplasty 2000;15(5):597.
9. Yoshino N, Takai S, Watanabe Y, et al. Total knee arthroplasty with long stem for treatment of nonunion after high tibial osteotomy. J Arthroplasty 2004;19(4):528.
10. Bae DK, Song SJ, Yoon KH. Total knee arthroplasty following closed wedge high tibial osteotomy. Int Orthop 2010;34(2):283.
11. Bergenudd H, Sahlstrom A, Sanzen L. Total knee arthroplasty after failed proximal tibial valgus osteotomy. J Arthroplasty 1997;12(6):635.
12. Gill T, Schemitsch EH, Brick GW, et al. Revision total knee arthroplasty after failed unicompartmental knee arthroplasty or high tibial osteotomy. Clin Orthop Relat Res 1995;321(12):10.
13. Kazakos KJ, Chatzipapas C, Verettas D, et al. Mid-term results of total knee arthroplasty after high tibial osteotomy. Arch Orthop Trauma Surg 2008;128(2):167.
14. Meding JB, Keating EM, Ritter MA, et al. Total knee arthroplasty after high tibial osteotomy. A comparison study in patients who had bilateral total knee replacement. J Bone Joint Surg Am 2000;82(9):1252.
15. Meding JB, Keating EM, Ritter MA, et al. Total knee arthroplasty after high tibial osteotomy. Clin Orthop Relat Res 2000;375(6):175.
16. Katz MM, Hungerford DS, Krackow KA, et al. Results of total knee arthroplasty after failed proximal tibial osteotomy for osteoarthritis. J Bone Joint Surg Am 1987;69(2):225.
17. Krackow KA, Holtgrewe JL. Experience with a new technique for managing severely overcorrected valgus high tibial osteotomy at total knee arthroplasty. Clin Orthop Relat Res 1990;258(9):213.
18. Scott CE, Davidson E, MacDonald DJ, et al. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. Bone Joint J 2015;97-B(4):532.
19. Saleh KJ, Sherman P, Katkin P, et al. Total knee arthroplasty after open reduction and internal fixation of fractures of the tibial plateau: a minimum five-year follow-up study. J Bone Joint Surg Am 2001;83-A(8):1144.
20. Weiss NG, Parvizi J, Trousdale RT, et al. Total knee arthroplasty in patients with a prior fracture of the tibial plateau. J Bone Joint Surg Am 2003;85-A(2):218.
21. Jain R. Complications of total knee arthroplasty after open reduction and internal fixation of fractures of the tibial plateau. J Bone Joint Surg Am 2002;84-A(3):497.
22. Papadopoulos EC, Parvizi J, Lai CH, et al. Total knee arthroplasty following prior distal femoral fracture. Knee 2002;9(4):267.
23. Atesok K, Doral MN, Whipple T, et al. Arthroscopy-assisted fracture fixation. Knee Surg Sports Traumatol Arthrosc 2011;19(2):320.
24. Hartigan DE, McCarthy MA, Krych AJ, et al. Arthroscopic-assisted reduction and percutaneous fixation of tibial plateau fractures. Arthrosc Tech 2015;4(1):e51.
25. Raynauld JP, Martel-Pelletier J, Haraoui B, et al. Risk factors predictive of joint replacement in a 2-year multicentre clinical trial in knee osteoarthritis using MRI: results from over 6 years of observation. Ann Rheum Dis 2011;70(8):1382.
26. Walther M, König A, Kirschner S, et al. Results of posterior cruciate-retaining unconstrained total knee arthroplasty after proximal tibial osteotomy for osteoarthritis. A prospective cohort study. Arch Orthop Trauma Surg 2000;120(3-4):166.
27. Scher C, Craig J, Nelson F. Bone marrow edema in the knee in osteoarthrosis and association with total knee arthroplasty within a three-year follow-up. Skeletal Radiol 2008;37(7):609.
28. Tanamas SK, Wluka AE, Pelletier JP, et al. Bone marrow lesions in people with knee osteoarthritis predict progression of disease and joint replacement: a longitudinal study. Rheumatology (Oxford) 2010;49(12):2413.
29. Hunter DJ, Gerstenfeld L, Bishop G, et al. Bone marrow lesions from osteoarthritis knees are characterized by sclerotic bone that is less well mineralized. Arthritis Res Ther 2009;11(1):R11.
30. Mont MA, Antonaides S, Krackow KA, et al. Total knee arthroplasty after failed high tibial osteotomy. A comparison with a matched group. Clin Orthop Relat Res 1994;299(2):125.
31. Parvizi J, Hanssen AD, Spangehl MJ. Total knee arthroplasty following proximal tibial osteotomy: risk factors for failure. J Bone Joint Surg Am 2004;86-A(3):474.
32. Vince K, Chivas D, Droll KP. Wound complications after total knee arthroplasty. J Arthroplasty 2007;22(4 Suppl 1):39.
33. Schmitz JP, Hollinger JO, Milam SB. Reconstruction of bone using calcium phosphate bone cements: a critical review. J Oral Maxillofac Surg 1999;57(9):1122.
34. Abrams GD, Alentorn-Geli E, Harris JD, et al. Treatment of a lateral tibial plateau osteochondritis dissecans lesion with subchondral injection of calcium phosphate. Arthrosc Tech 2013;2(3):e271.
35. Yuan H, Li Y, de Bruijn JD, et al. Tissue responses of calcium phosphate cement: a study in dogs. Biomaterials 2000;21(12):1283.
36. Kurashina K, Kurita H, Hirano M, et al. In vivo study of calcium phosphate cements: implantation of an alpha-tricalcium phosphate/dicalcium phosphate dibasic/tetracalcium phosphate monoxide cement paste. Biomaterials 1997;18(7):539.
37. Sarkar MR, Wachter N, Patka P, et al. First histological observations on the incorporation of a novel calcium phosphate bone substitute material in human cancellous bone. J Biomed Mater Res 2001;58(3):329.
38. Wang L, Barbieri D, Zhou H, et al. Effect of particle size on osteoinductive potential of microstructured biphasic calcium phosphate ceramic. J Biomed Mater Res A 2015;103:1919.
39. Yuan H, Yang Z, De Bruij JD, et al. Material-dependent bone induction by calcium phosphate ceramics: a 2.5-year study in dog. Biomaterials 2001;22(19):2617.
40. Low KL, Tan SH, Zein SH, et al. Calcium phosphate-based composites as injectable bone substitute materials. J Biomed Mater Res B Appl Biomater 2010;94(1):273.
41. Ambrosio L, Guarino V, Sanginario V, et al. Injectable calcium-phosphate-based composites for skeletal bone treatments. Biomed Mater 2012;7(2):024113.
42. Lewis G. Viscoelastic properties of injectable bone cements for orthopaedic applications: state-of-the-art review. J Biomed Mater Res B Appl Biomater 2011;98(1):171.