Beta tricalcium phosphate shows superior absorption rate and osteoconductivity compared to hydroxyapatite in open wedge high tibial osteotomy

Running title: Comparisons of Synthetic Spacers in High Tibial Osteotomy

[1]Jun Onodera, MD, PhD; [1]Eiji Kondo, MD, PhD; [2]Nobuyuki Omizu, MD, PhD; [2]Daisuke Ueda, MD; [2]Tomonori Yagi, MD, PhD; [1]Kazunori Yasuda, MD, PhD

From [1]the Department of Sports Medicine and Joint Surgery, Hokkaido University Graduate School of Medicine, Sapporo, Hokkaido, Japan, and [2]the Department of Orthopaedic Surgery, Yamanote-dori Yagi Hospital, Sapporo, Hokkaido, Japan

*Address correspondence to: Eiji Kondo, MD, PhD, Associate Professor, Department of Sports Medicine and Joint Surgery, Hokkaido University Graduate School of Medicine, Kita-15 Nishi-7, Kita-ku, Sapporo, 060-8638, Japan.

Tel: +81-11-706-7211, Fax: +81-11-706-7822, E-mail: eijik@med.hokudai.ac.jp

Acknowledgments

This research was supported in part by grants-in-aid for scientific research (24592218) from the Ministry of Education, Science and Culture, Japan.

Abstract

Purpose: The purpose of this study was to clinically and radiologically compare the utility, osteoconductivity, and absorbability of hydroxyapatite (HAp) and beta-tricalcium phosphate (TCP) spacers in medial open wedge high tibial osteotomy (HTO).

Methods: Thirty-eight patients underwent medial open wedge HTO with a locking plate. In the first 19 knees, a HAp spacer was implanted in the opening space (HAp group). In the remaining 19 knees, a TCP spacer was implanted in the same manner (TCP group). All patients underwent clinical and radiological examinations before surgery and at 18 months after surgery.

Results: Concerning the background factors, there were no statistical differences between the two groups. Postoperatively, the knee score significantly improved in each group. Concerning the postoperative knee alignment and clinical outcome, there was no statistical difference in each parameter between the two groups. Regarding the osteoconductivity, the modified van Hemert's score of the TCP group was significantly higher (p=0.0009) than that of the HAp group in the most medial osteotomy zone. The absorption rate was significantly greater in the TCP group than in the HAp group (p=0.00039).

Conclusions: The present study demonstrated that a TCP spacer was significantly superior to a HAp spacer concerning osteoconductivity and absorbability at 18 months after medial open wedge HTO.

Level of Evidence: III, Retrospective comparative study

Keywords: Open wedge high tibial osteotomy; Beta-tricalcium phosphate; Hydroxyapatite; Wedge-shaped spacer; Knee osteoarthritis

Introduction

High tibial osteotomy (HTO) has been a useful surgical option for medial osteoarthritis (OA) of the knee. Recently, the medial open wedge HTO with a locking plate has attracted a great deal of attention [3,7,14,20,26,28,34,35]. However, the open wedge HTO has the disadvantage that a large vacant space is left in the proximal tibia after surgery [2,16,33]. In addition, it is known that it takes a long period, a few months or more, until the open space created in the tibia after alignment correction is filled with regenerated bone [21,36]. Recently, therefore, a wedge-shaped spacer made from hydroxyapatite (HAp) or beta-tricalcium phosphate (TCP) has been used to fill the vacant space in the open wedge HTO [21,32,34,36]. However, it is necessary for a spacer for the open wedge HTO to have not only sufficient strength but also high osteoconductivity and absorbability. The former ability is one of the minimum requirements of a synthetic bone [22]. The latter ability is necessary to avoid a possible risk that the strong spacer implanted in the tibia may cause an obstacle in revision surgery after HTO [32]. Therefore, it can be useful to assess the osteoconductivity and absorbability of ceramic spacers after medial open wedge HTO. A number of previous basic studies reported that HAp and TCP ceramics have excellent osteoconductivity under various experimental conditions, while they have different absorbability

[6,9,12,15,19,23,24,27,43,45]. However, the experimental conditions used in these basic studies are different from the biological and biomechanical environments surrounding synthetic spacers implanted into the tibia of patients. Therefore, commonly, the osteoconductivity and absorbability of the HAp or TCP spacers must be evaluated in each clinical lesion where the spacer is implanted. However, no clinical study so far has compared the osteoconductivity and absorbability of the HAp or TCP spacers in the tibia with medial open wedge HTO. Based on previous studies, it has been hypothesized that the osteoconductivity and absorbability of the TCP spacer might be higher in comparison to the HAp spacer. The purpose of this study is to test this hypothesis.

Materials and Methods

A retrospective comparative study was performed with 45 patients who underwent medial open wedge HTO with a locking compression plate (Tomofix, Synthes, Bettlach, Switzerland). Inclusion criteria used in this study involved patients who had persistent pain due to medial compartment OA or spontaneous osteonecrosis of the medial femoral condyle, after they received conservative treatment for 3 months or more. Exclusion criteria in this study included (1) patients whose lateral femorotibial angle (FTA) was more than 185°; (2) patients who had an extension loss of more than 15°; (3)

patients who had a range of knee motion less than 130°; (4) patients who had a history of infection in the knee; (5) patients who had severe OA in the patellofemoral joint, (6) patients who had anterior cruciate ligament insufficiency or varus/valgus instability of more than 10°.

Between 2009 and 2010, 23 patients were enrolled in this study. In these patients, we used a HAp spacer (NEOBONE, Covalent Materials, Tokyo, Japan) in HTO. Between 2010 and 2011, 22 patients were enrolled. In these patients, a TCP spacer (OSferion, Olympus-Terumo Biomaterials, Tokyo, Japan) was used in HTO. The biomaterial characteristics of the HAp and TCP ceramics used are shown in Table 1. In each patient, computed digital radiographs (Fujifilm, Miyagi, Japan) were taken to evaluate alignment changes before and immediately after surgery. Clinical and radiological follow-up examinations were performed at 18 months after surgery. The evaluations of the spacer were not obstructed by the implanted plate, because it had been removed at approximately 1 year after HTO. However, in the first group, 4 patients did not have the plate removed so only the remaining 19 patients (83%) could be evaluated as the HAp group. In the second group, 3 patients did not have the plate removed, leaving the remaining 19 patients (86%) as the TCP group. The follow-up period averaged 18 (8) months in the HAp group, and 17 (7) months in the TCP group.

Patient Demographics

In the HAp group, there were 14 women and 5 men with a mean age of 61.0 years at the time of surgery. Concerning the radiological OA grade, this group included 8 knees of grade 2 and 11 knees of grade 3 [18]. We found spontaneous osteonecrosis in 1 knee. In the TCP group, there were 17 women and 2 men with a mean age of 60.5 years. Regarding the OA grade, this group included 8 knees of grade 2, 10 knees of grade 3, and 1 knee of grade 4. We found spontaneous osteonecrosis in 1 knee. The background factors of the 2 groups are shown in Table 2, including body mass index (BMI), and % young adult mean (YAM) of bone mineral density (BMD). There were no statistical differences in the background factors between the 2 groups. The clinical and radiological status of the 2 groups is shown in Table 3, including range of knee motion, knee evaluation score (Japan Orthopaedic Association: JOA score), the OA grade, FTA, weight-bearing line (WBL), the tibial slope, and the Insall-Salvati ratio [4,44]. There were no statistical differences between the 2 groups.

Procedure of Medial Open Wedge HTO

The proximal tibia was exposed through a 7-cm medial longitudinal incision. Then, we performed a biplanar osteotomy of the tibia, which consisted of an oblique HTO and a frontal plane osteotomy behind the tibial tubercle [36], using a micro bone saw. Then, the oblique osteotomy site was gradually opened by use of a specially designed spreader under fluoroscopic control so that the valgus angulation of the knee became 10°.

From a rectangular block of HAp or TCP, we intra-operatively created a wedge-shaped spacer using a custom-made circular saw system (Fig. 1A). During each surgery, we created 2 wedge-shaped spacers, and they were implanted parallel into the anterior part and posterior part of the opening (Fig. 1B). Then, we fixed the tibia with a locking compression plate (Tomofix, Synthes) by inserting 8 locking screws (Fig. 1C).

Postoperative Rehabilitation

Straight leg raising and quadriceps setting exercises as well as active and passive knee motion exercises were encouraged from the next day after surgery. Partial weight-bearing on the tibia was permitted with crutches at 2 weeks after surgery. Full weight-bearing was allowed at 4 weeks after surgery.

Clinical and Radiological Evaluations

The patients were evaluated using the JOA Score [4,44]. The clinical evaluations were carried out twice, before surgery and at the final follow-up period. The radiological stage of osteoarthritis was assessed according to the Kellgren-Lawrence grading system [18] based on an anteroposterior radiograph of the knee.

The FTA was measured on an anteroposterior weight-bearing radiograph of a single leg, with the knee joint in extension. The WBL percentages and the entire leg length were measured on an anteroposterior radiograph of the whole lower limb taken with a long cassette in the one-leg standing position. The FTA was defined as the angle between the axis of the femoral shaft and the axis of the tibial shaft on the fibular side. To calculate the WBL, a line was drawn from the center of the femoral head to the middle point of the proximal talar joint surface. The WBL percentage was defined as the horizontal distance from the WBL to the medial edge of the tibial plateau, divided by the width of the tibial plateau. The entire leg length was defined as the distance between the top of the femoral head and the center of the tibial plafond. The Insall-Salvati index [25] and tibial slope [29] were estimated on lateral radiographs. The Insall-Salvati ratio, defined as the length of the patellar tendon (from the inferior pole of the patella to the tibial tubercle) divided by the patellar height (longest coronal dimension of the patella), was calculated. The tibial slope was measured as the angle between the line perpendicular to the mid-diaphysis of the tibia and the posterior inclination of the tibial plateau on the lateral view. Test–retest reliability was assessed by calculation of Pearson correlation coefficient. A test–retest reliability experiment for each measurement confirmed a high reliability between time point one and two with $P<0.01$ and $r = 0.90$ demonstrating a strong correlation.

To assess the osteoconductivity on an anteroposterior radiograph, we drew a triangle that showed the wedge-shaped space created by open wedge HTO, and divided this triangle into 4 zones (Fig. 2) [8]. The most medial zone was named “Zone I”. Then, we named the next 3 zones “Zones II, III, and IV (the most lateral zone)”, respectively. In each zone, we graded new bone formation in a thin space between the bone surface created by osteotomy opening and the inserted spacer surface, using the modified van Hemert’s rating system [39] (Fig. 3): Namely, 0 point was given when an osteotomy line on the tibia was as clear as that immediately after surgery and we could not find any new bone formation on neither the proximal nor distal surface of the spacer: One point was given when an osteotomy line on the tibia became unclear but a distinct lucent line was clearly visible on both the proximal and distal surface of the spacer: Two points were given when a blurred lucent line was visible in a limited part on both the proximal and distal surface of the spacer: Three points were given when a blurred lucent line was clearly visible on one surface of the spacer but not visible at all on the other surface:

Four points were given when a blurred lucent line was visible in a limited part on one surface of the spacer but not visible at all on the other surface: Five points were given when no lucent line was visible at all on either surface of the spacer.

To assess the absorbability of each spacer, the area of the implanted spacer on the anteroposterior radiograph was measured with the NIH Image J (National Institutes of Health, Bethesda, Maryland) immediately after surgery (A0) and at the final follow-up period (A1). We defined a rate given by the formula, (A0-A1)/A0, as the "absorption rate" of each implanted spacer. First, a digital image file of a radiograph was opened by the NIH image J. Then, for setting measurement scale, the maximum joint width of the proximal tibia was marked on the anteroposterior radiograph as a baseline. The automated threshold included only the spacer area. Finally, the area of the spacer was calculated.

Prior approval was given from the Investigational Review Board, the Ethics Committee of Hokkaido University (Reference number: 012-0360).

Statistical Analysis

All data were shown as means with standard deviations. For each parameter, unpaired Student's t test and χ^2 test were performed between the two groups. The Pearson correlation coefficient was used to characterize the size of the wedge and the osteoconductivity. A commercially available software program (StatView, SAS Institute, Cary, North Carolina) was used for statistical calculation. The significance level was set at p=0.05. Concerning the absorption rate, reproducibility was high as represented by both the intra-observer (mean ICC = 0.93; range 0.89–0.97) and the inter-observer (mean ICC = 0.87; range 0.8–0.93) reliability measurements.

Results

Comparison of postoperative alignment after HTO

The size of the wedge spacer averaged 13.2 (1.9) mm and 12.1 (2.3) mm in the HAp and TCP groups, respectively (Fig. 4). There was no significant difference in the size of each spacer. Immediately after surgery (Table 4), concerning the mean opening angle, the opening distance, the FTA, the tibial slope, and Insall-Salvati ratio, there was no significant difference in each parameter between the 2 groups.

At the final follow-up examination (Table 5), the FTA averaged 169.8° in both groups. The FTA, the tibial slope, and the Insall-Salvati ratio did not significantly change between the 2 examination periods in each group. In addition, again, there was no significant difference in each parameter between the 2 groups.

Comparison of osteoconductivity and absorbability of the HAp or TCP spacers

Concerning the osteoconductivity, the modified van Hemert's score in the TCP group (4.5 (0.8) points) was significantly higher (p=0.0009) than that of the HAp group (3.2 (1.3) points) in zone 1(Fig. 5), while there were no significant differences between the 2 groups in the other zones. The absorption rate averaged 0.9 (19.6) % in the HAp group and 25.3 (18.5) % in the TCP group. The absorption rate was significantly greater in the TCP group than in the HAp group (p=0.00039). There was no significant relationship between the size of the wedge and the osteoconductivity in the HAp and TCP groups.

Comparison of postoperative clinical results of HTO

All the patients underwent the second surgery for removal of the fixation plate at a mean period of 12 (1.6) and 13 (3.7) months in the HAp and TCP groups, respectively. There were no intra- and post-operative complications in either group. In the final clinical examination (Table 5), the medial pain in the knee joints had resolved in all cases. Postoperatively, the mean JOA score significantly improved at the final follow-up in the both groups. There were no significant differences between the 2 groups.

Discussion

The most important finding of the present study was that the osteoconductivity in the TCP group was significantly higher than in the HAp group in the most medial osteotomy zone. The absorption rate was also significantly greater in the TCP group than in the HAp group. Postoperatively, the knee score improved significantly in each group. Regarding the knee alignment, there was no statistical difference in each parameter between the HAp and TCP groups.

It was considered why the osteoconductivity was superior in the TCP group compared with the HAp group. According to the manufacturer's information, the HAp ceramics have 75% porosity and interconnected macropores. However, this HAp does not have micropores in the walls of its macropores. On the other hand, the TCP ceramics used in this study have 60% porosity, and macro and microstructures, with interpore connections. Previously, several researchers have reported an important role of the microstructure in the behavior of bone cells and bone metabolism [12,31,40]. Lu et al [27] reported on implanted cylinders of HAp and TCP ceramics in the cortical, cancellous, and medullar bone sites using rabbits. The bone/implant interface contact was better in TCP than in HAp, especially in the cortical site. In this study, the osteoconductivity of the TCP group was significantly higher than that of the HAp group in the most medial osteotomy zone. This zone corresponds to the ‘cortical bone’ site. From these results, it is considered that the micropores of the TCP provided a better substrate or microenvironment for osteoblastic cell formation [40,41].

TCP is thought to be largely degraded by hydrolysis in vitro and is absorbed more rapidly than HAp in vivo [11,13,41]. There may be many other factors that influence the in vivo degradation of materials [6,10,12,22,40], and the role of such factors has not yet been clarified. It has been suggested that the mechanism of bioceramic resorption involves two processes, which are solution-mediated and cell-mediated disintegration [10,15]. Solution-mediated disintegration is associated with the composition of the material itself as well as the surrounding environment [17]. Cell-mediated disintegration is mainly caused by osteoclasts [42]. Histological assessment [43] revealed that numerous osteoclasts were present on the surface of the TCP. In the HAp, however, few osteoclasts were detected. This may cause the above-described differences in the clinical lesion after medial open wedge HTO.

Previous basic studies investigated the absorbability of TCP ceramics with several porosities [11]. Lu et al [27] reported on implanted cylinders of TCP with 52% porosity in the rabbit femur. The material degradation rate of the TCP was 29%, 55%, and 75% in the cortical, cancellous, and medullar bone, respectively, at 24 weeks after implantation. In human studies, Ogose et al [30] reported on implantation of TCP with 75% porosity after excision of bone tumor. They reported that all cases displayed almost total resorption of TCP on radiograph at 26 months after surgery. However, Altermatt et al [1] reported that most implanted TCP with 60% porosity remains at least 7 years in calcaneal bone defects. Regarding implantation in the HTO, Tanaka et al [37] reported implantation in patients of TCP blocks with 75% and 60% porosities in medial open wedge HTO. In their report, nearly complete resorption of TCP was obtained within 3.5 years. However, in this study, it was noted that the absorption rate of the TCP spacer averaged only 25% at 18 months after surgery. Therefore, the absorbability of the TCP may depend on its porosity, volume, and shape, as well as the implant location.

Medial open wedge HTO can be performed without any spacer [26,35]. However, correction loss and screw breakage after open wedge HTO have been reported [38]. It is widely agreed that autografting is the gold standard and allografting is a secondary option [11,13,16]. However, autografts have some problems, including donor site morbidity, while allografts have disadvantages such as the potential to provoke an immune response and the risk of disease transmission [5]. The main disadvantage of HTO is the long period of rehabilitation needed after surgery [26,35]. However, Takeuchi et al [36] reported that an early weight-bearing exercise program enables full weight bearing at 2 weeks after medial open wedge HTO with Tomofix plate (Synthes) and TCP wedges. Therefore, based on these advantages, we expect a spacer to enhance bony healing after medial open wedge HTO. However, an implanted spacer may become a serious problem in various revision surgeries in the future. Therefore, we believe that an ideal spacer for medial open wedge HTO must have high clinical utility, high osteoconductivity, and high absorbability. The present study showed that there were no significant differences concerning the clinical utility between the HAp and TCP spacers in medial open wedge HTO. From the viewpoint of clinical utility, this study suggested that these spacers, with excellent biocompatibility, are equally useful for medial open wedge HTO with a locking plate.

There are some limitations in this study. First, the follow-up period averaged only 18 months. Therefore, at the present time, we cannot speculate whether there will be differences between the HAp and TCP ceramics in long-term outcome of knee function, and absorbability. Second, only anteroposterior radiographs were used for bone union evaluation. Third, we had no histological evaluation of the bone union site. However, these preliminary short-term follow up human data will be a turning point for the issue of bone union for medial open wedge HTO. These results suggest that the TCP spacer is superior to the HAp spacer concerning osteoconductivity and absorbability. However, middle- and long-term follow-up evaluations are needed to confirm the superiority found in the present study.

Conclusion

The present study showed that there were no significant differences concerning the clinical utility between the HAp and TCP spacers in open wedge HTO at 18 months after surgery. The osteoconductivity of the TCP spacer was slightly but significantly higher than that of the HAp spacer after HTO, and the absorbability of the TCP spacer was also significantly greater than that of the HAp spacer after HTO.

References

1. Altermatt S, Schwöbel M, Pochon JP (1992) Operative treatment of solitary bone cysts with tricalcium phosphate ceramic. A 1 to 7 year follow-up. Eur J Pediatr Surg 2:180-182
2. Amendola A, Panarella L (2005) High tibial osteotomy for the treatment of unicompartmental arthritis of the knee. Orthop Clin North Am 36:497-504
3. Amis AA (2013) Biomechanics of high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 21:197-205
4. Aoki Y, Yasuda K, Mikami S et al (2006) Inverted V-shaped high tibial osteotomy compared with closing-wedge high tibial osteotomy for osteoarthritis of the knee. Ten-year follow-up result. J Bone Joint Surg Br 88:1336-1340
5. Bauer TW, Muschler GF (2000) Bone graft materials. An overview of the basic science. Clin Orthop Relat Res 371:10-27
6. Billström GH, Blom AW, Larsson S, Beswick AD (2013) Application of scaffolds for bone regeneration strategies: current trends and future directions. Injury. 44:S28-33
7. Bonnin MP, Laurent JR, Zadegan F, Badet R, Pooler Archbold HA, Servien E (2013) Can patients really participate in sport after high tibial osteotomy? Knee Surg

Sports Traumatol Arthrosc 21:64-73

8. Brosset T, Pasquier G, Migaud H, Gougeon F (2011) Opening wedge high tibial osteotomy performed without filling the defect but with locking plate fixation (TomoFix™) and early weight-bearing: prospective evaluation of bone union, precision and maintenance of correction in 51 cases. Orthop Traumatol Surg Res 97:705-711

9. Chatterjea A, van der Stok J, Danoux CB et al (2013) Inflammatory response and bone healing capacity of two porous calcium phosphate ceramics in critical size cortical bone defects. J Biomed Mater Res A doi: 10.1002/jbm.a.34815.

10. Chazono M, Tanaka T, Kitasato S et al (2008) Electron microscopic study on bone formation and bioresorption after implantation of beta-tricalcium phosphate in rabbit models. J Orthop Sci 13:550-555

11. Chazono M, Tanaka T, Komaki H, Fujii K (2004) Bone formation and bioresorption after implantation of injectable beta-tricalcium phosphate granules-hyaluronate complex in rabbit bone defects. J Biomed Mater Res A 70:542-549

12. Dorozhkin SV (2010) Bioceramics of calcium orthophosphates. Biomaterials 31:1465-85

13. Finkemeier CG (2002) Bone-grafting and bone-graft substitutes. J Bone Joint Surg

Am 84-A:454-464

14. Floerkemeier S, Staubli AE, Schroeter S, Goldhahn S, Lobenhoffer P (2013) Outcome after high tibial open-wedge osteotomy: a retrospective evaluation of 533 patients. Knee Surg Sports Traumatol Arthrosc 21:170-80
15. Fujita R, Yokoyama A, Kawasaki T, Kohgo T (2003) Bone augmentation osteogenesis using hydroxyapatite and beta-tricalcium phosphate blocks. J Oral Maxillofac Surg 61:1045-1053
16. Gouin F, Yaouanc F, Waast D, Melchior B, Delecrin J, Passuti N (2010) Open wedge high tibial osteotomies: Calcium-phosphate ceramic spacer versus autologous bonegraft. Orthop Traumatol Surg Res 96:637-45
17. Juhasz JA, Best SM, Auffret AD, Bonfield W (2008) Biological control of apatite growth in simulated body fluid and human blood serum. J Mater Sci Mater Med 19:1823-1829
18. Kellgren JH, Lawrence JS (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16:494-502
19. Klein CP, de Blieck-Hogervorst JM, Wolke JG, de Groot K (1990) Studies of the solubility of different calcium phosphate ceramic particles in vitro. Biomaterials 11:509-512

20. Kohn L, Sauerschnig M, Iskansar S, Lorenz S, Meidinger G, Imhoff AB, Hinterwimmer S (2013) Age does not influence the clinical outcome after high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 21:146-51
21. Koshino T, Murase T, Saito T (2003) Medial opening-wedge high tibial osteotomy with use of porous hydroxyapatite to treat medial compartment osteoarthritis of the knee. J Bone Joint Surg Am 85-A:78-85
22. Hannink G, Arts JJ (2011) Bioresorbability, porosity and mechanical strength of bone substitutes: what is optimal for bone regeneration? Injury 42:S22-5
23. Hench LL, Ethridge EC (1982) Biomaterials, an interfacial approach, in Noordergraaf A (ed):Biophysics and Bioengineering Series. New York, NY: Academic Press 126-148
24. Hwang JW, Park JS, Lee JS et al (2012) Comparative evaluation of three calcium phosphate synthetic block bone graft materials for bone regeneration in rabbit calvaria. J Biomed Mater Res B Appl Biomater 100:2044-52
25. Insall JN, Salvati E (1971) Patella position in the normal knee joint. Radiology 101:101-4
26. Lobenhoffer P, Agneskirchner JD (2003) Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 11:132-138

27. Lu JX, Gallur A, Flautre B et al (1998) Comparative study of tissue reactions to calcium phosphate ceramics among cancellous, cortical, and medullar bone sites in rabbits. J Biomed Mater Res 42:357-367

28. McNamara I, Birmingham TB, Fowler PJ, Giffin JR (2013) High tibial osteotomy: evolution of research and clinical applications--a Canadian experience. Knee Surg Sports Traumatol Arthrosc 21:23-31

29. Moore TM, Harvey JP Jr (1974) Roentgenographic measurement of tibial-plateau depression due to fracture. J Bone Joint Surg Am 56A:155-60

30. Ogose A, Hotta T, Kawashima H et al (2005) Comparison of hydroxyapatite and beta tricalcium phosphate as bone substitutes after excision of bone tumors. J Biomed Mater Res B Appl Biomater 72:94-101

31. Okuda T, Ioku K, Yonezawa I et al (2007) The effect of the microstructure of beta-tricalcium phosphate on the metabolism of subsequently formed bone tissue. Biomaterials 28:2612-2621

32. Ozalay M, Sahin O, Akpinar S et al (2009) Remodeling potentials of biphasic calcium phosphate granules in open wedge high tibial osteotomy. Arch Orthop Trauma Surg 129:747-752

33. Pape D, Kohn D, van Giffen N, Hoffmann A, Seil R, Lorbach O (2013) Differences

in fixation stability between spacer plate and plate fixator following high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 21:82-9

34. Smith JO, Wilson AJ, Thomas NP (2013) Osteotomy around the knee: evolution, principles and results. Knee Surg Sports Traumatol Arthrosc 21:3-22

35. Staubli AE, De Simoni C, Babst R, Lobenhoffer P (2003) TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia--early results in 92 cases. Injury 34 Suppl 2:B55-62

36. Takeuchi R, Ishikawa H, Aratake M et al (2009) Medial opening wedge high tibial osteotomy with early full weight bearing. Arthroscopy 25:46-53

37. Tanaka T CM, Komaki H (2006) Clinical application of b-tricalcium phosphate in human bone defects. Jikeikai Med 53:45-53

38. Valkering KP, van den Bekerom MP, Kappelhoff FM et al (2009) Complications after tomofix medial opening wedge high tibial osteotomy. J Knee Surg 22:218-225

39. van Hemert WL, Willems K, Anderson PG et al (2004) Tricalcium phosphate granules or rigid wedge preforms in open wedge high tibial osteotomy: a radiological study with a new evaluation system. Knee 11:451-456

40. Velard F, Braux J, Amedee J, Laquerriere P (2013) Inflammatory cell response to calcium phosphate biomaterial particles: an overview. Acta Biomater 9:4956-63

41. Walsh WR, Vizesi F, Michael D et al (2008) Beta-TCP bone graft substitutes in a bilateral rabbit tibial defect model. Biomaterials 29:266-71

42. Wenisch S, Stahl JP, Horas U et al (2003) In vivo mechanisms of hydroxyapatite ceramic degradation by osteoclasts: fine structural microscopy. J Biomed Mater Res A 67:713-718

43. Yamasaki N, Hirao M, Nanno K et al (2009) A comparative assessment of synthetic ceramic bone substitutes with different composition and microstructure in rabbit femoral condyle model. J Biomed Mater Res B Appl Biomater 91:788-798

44. Yasuda K, Majima T, Tsuchida T, Kaneda K (1992) A ten- to 15-year follow-up observation of high tibial osteotomy in medial compartment osteoarthrosis. Clin Orthop Relat Res 282:186-195

45. Yuan H, Fernandes H, Habibovic P et al (2010) Osteoinductive ceramics as a synthetic alternative to autologous bone grafting. Proc Natl Acad Sci U S A 3;107:13614-9

Figure Legends

Fig. 1

Two HAp or two TCP wedges were formed in a triangle pole (a) equivalent to the size of the opening and then inserted into the osteotomy site to fit into the medial cortical bone edge (b). (c) After implantation of the ceramic spacer, a low profile locking plate (TomoFix, Synthes) was fixed in place with 8 locking screws.

Fig. 2

A triangle on digitized anteroposterior radiographs, with the sides of the triangle being along the borders and corner of the osteotomy. This triangular surface was then divided into four zones of the same surface area on the radiographs. These zones were numbered 1 to 4, starting from the medial cortex.

Fig. 3

The modified van Hemert's rating system: Namely, 0 point was given when an osteotomy line on the tibia was as clear as that immediately after surgery and we could not find any new bone formation on neither the proximal nor distal surface of the spacer: One point was given when an osteotomy line on the tibia became unclear but a distinct lucent line was clearly visible on both the proximal and distal surface of the spacer: Two points were given when a blurred lucent line was visible in a limited part on both the proximal and distal surface of the spacer: Three points were given when a blurred lucent line was clearly visible on one surface of the spacer but not visible at all on the other surface: Four points were given when a blurred lucent line was visible in a limited part on one surface of the spacer but not visible at all on the other surface: Five points were given when no lucent line was visible at all on either surface of the spacer.

Fig. 4

Diagrams of the size of each spacer for the HAp and TCP groups. The size of the wedge spacer averaged 13.2 (1.9) mm and 12.1 (2.3) mm in the HAp and TCP groups, respectively (Fig. 4). There was no significant difference in the size of each spacer.

Fig. 5

Concerning osteoconductivity, the modified van Hemert's score of the TCP group was significantly higher (p=0.015) than that of the HAp group in the most medial osteotomy zone, while there were no significant differences between the 2 groups in the other zones.

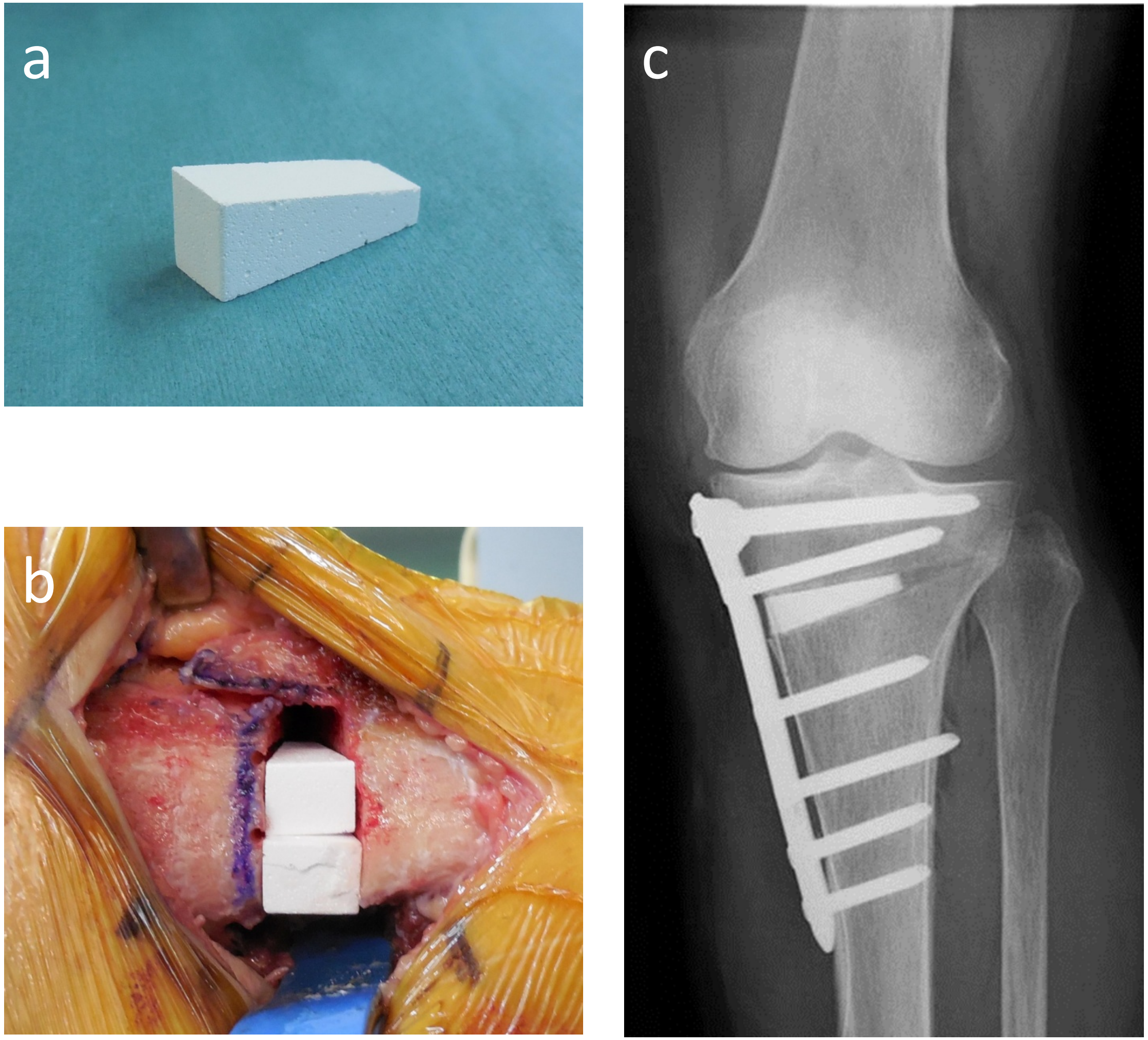


Figure 1

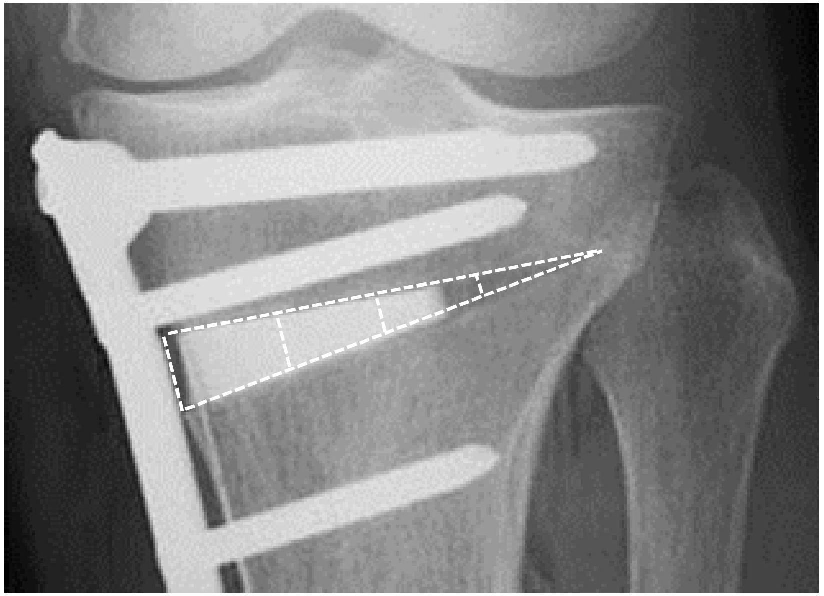
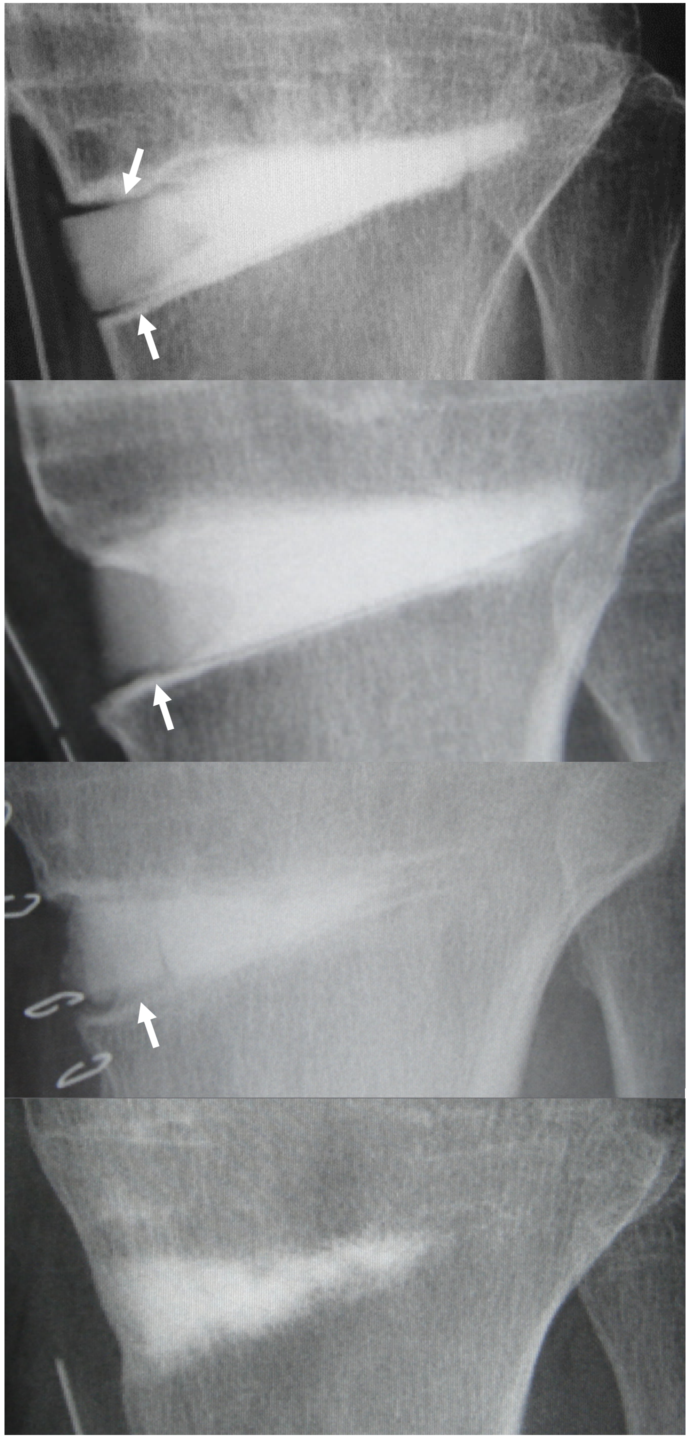


Figure 2



2 points

3 points

4 points

5 points

Figure 3

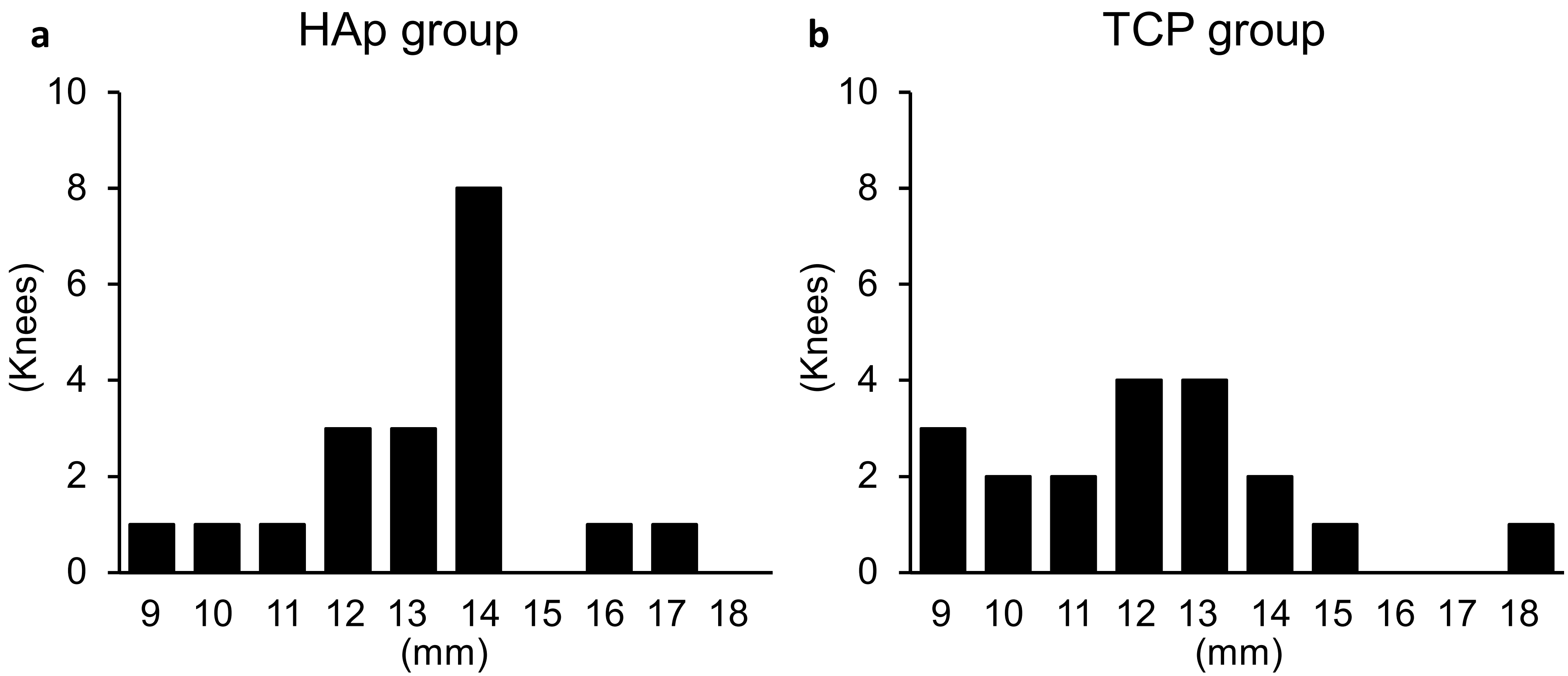
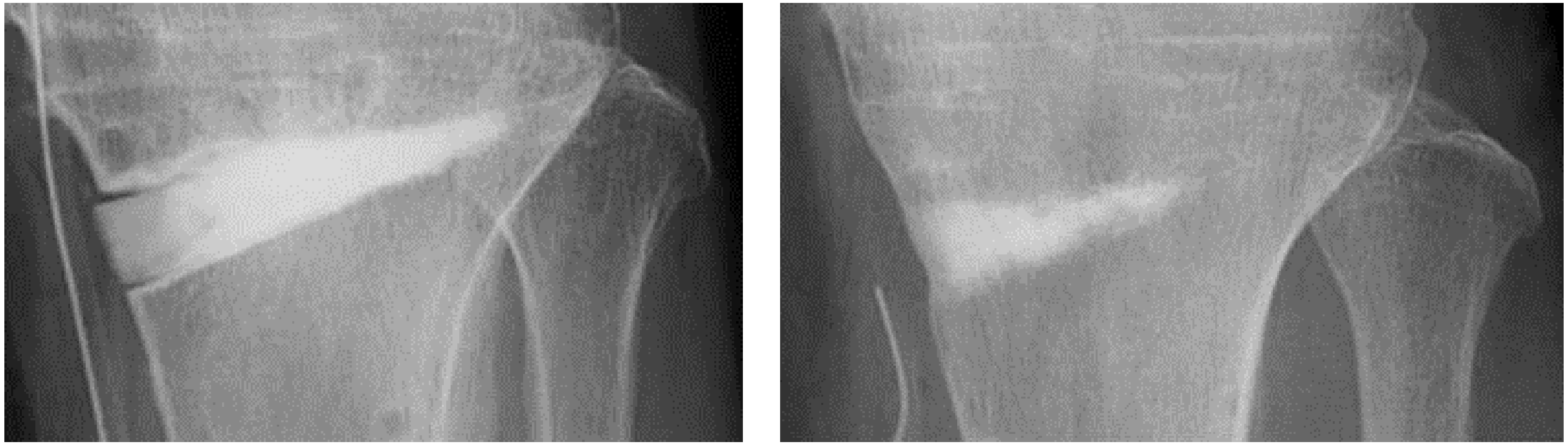

a
HAp group
10
8
6
4
2
0
(Knees)
9 10 11 12 13 14 15 16 17 18
(mm)
b
TCP group
10
8
6
4
2
0
(Knees)
9 10 11 12 13 14 15 16 17 18
(mm)

Figure 4



HAp group TCP group

Figure 5

Table 1.

Biomaterial characteristics of both ceramics

	HAp	TCP
Chemical formula	$Ca_{10}(PO_4)_6(OH)_2$	$Ca_3(PO_4)_2$
Compressive Strength (MPa)	12	20
Porosity (%)	75	60
Macropore (micrometer)	100–300	100–400
Micropore (micrometer)	none	~5

Table 2.

Background factor of patients

	HAp group	TCP group	p value
Age (years)	61.0 (7.0)	60.5 (5.9)	n.s.
Male/Female (patients)	5/14	2/17	n.s.
Height (cm)	156.3 (7.6)	155.6 (9.6)	n.s.
Weight (kg)	69.2 (15.3)	67.6 (14.3)	n.s.
BMI (kg/m^3)	28.3 (5.2)	27.8 (4.4)	n.s.
YAM (%)	88.3 (16.7)	92.9 (11.7)	n.s.

Mean (Standard deviation)

Table 3.

Comparisons of preoperative status of the patients

	HAp group	TCP group	p value
Ext. angle (°)	4.5 (5.7)	3.9 (5.9)	n.s.
Flex. angle (°)	140.4 (7.9)	140.8 (11.8)	n.s.
JOA score (points)	65.6 (8.4)	67.3 (8.6)	n.s.
OA grade (patients)			n.s.
Grade 0	0	0	
Grade 1	0	0	
Grade 2	8	8	
Grade 3	11	10	
Grade 4	0	1	
FTA (°)	180.1 (3.1)	179.4 (3.8)	n.s.
WBL (%)	26.4 (13.0)	27.7 (12.0)	n.s.
Tibial slope (°)	9.1 (3.6)	7.2 (3.4)	n.s.
Insall-Salvati ratio (%)	0.8 (0.1)	0.9 (0.2)	n.s.
Entire leg length (mm)	741.3 (38.0)	732.3 (19.6)	n.s.

Table 4.

Comparison of postoperative alignment immediately after surgery

	HAp group	TCP group	p value
Opening angle (°)	11.2 (3.2)	10.4 (3.5)	n.s.
Opening distance between the osteotomy sites (mm)	13.5 (1.7)	12.5 (2.4)	n.s.
FTA (°)	168.9 (2.6)	169.0 (2.1)	n.s.
Tibial slope (°)	13.7 (4.7)	11.4 (3.7)	n.s.
Insall-Salvati ratio (%)	0.8 (0.1)	0.9 (0.2)	n.s.

Table 5.

Comparison of postoperative clinical results of HTO

	HAp group	TCP group	p value
Ext. angle (°)	1.6 (4.1)	2.2 (4.9)	n.s.
Flex. angle (°)	143.2 (7.9)	141.4 (8.5)	n.s.
JOA score (points)	91.1 (10.4)	93.5 (6.6)	n.s.
FTA (°)	169.8 (2.8)	169.8 (2.9)	n.s.
WBL (%)	69.0 (8.8)	70.5 (14.6)	n.s.
Tibial slope (°)	13.7 (3.9)	11.5 (4.5)	n.s.
Insall-Salvati ratio (%)	0.9 (0.1)	0.9 (0.1)	n.s.
Entire leg length (mm)	747.0 (41.4)	739.3 (29.5)	n.s.