Although the outcomes of total knee arthroplasty (TKA) are excellent worldwide, management of bone loss is a significant challenge during TKA. Operative treatments for bone loss include the use of cement, autologous bone grafts, allografts, megaprostheses, hinged prostheses, and metal augments. Because autologous bone is generally available in primary TKA, even when deformities are severe, autologous bone grafting is commonly performed. Recently, metal augments have been used to replace small bone defects. Although metal augments for bone defects are available in various sizes, surgeons sometimes must resect additional recipient bone to match the shape of the augment. Further, the difference in elasticity between metal and bone may cause stress shielding and contribute to bone loss. On the other hand, the advantages of autologous bone grafting for tibial defects in primary TKA include biocompatibility, ligament restoration, graft availability, and reattachment of the medial cruciate ligament to the tibia. Additional advantages of autologous bone grafting include union, knee alignment, and clinical outcomes of patients treated with autologous bone grafting for medial tibial defects in primary total knee arthroplasty.
autologous bone grafting include a lower risk of infection than with allograft,⁹ ease of use, and greater appeal to patients and surgeons compared with allograft. Further, autologous bone grafting is more economical than augments and allografts. Potential limitations of autologous bone grafting include possible nonunion, lack of available graft bone, and bone resorption.¹⁰ The union rate for this procedure in primary TKA is not well known because few studies have been performed, the number of cases was limited, and most procedures were revised TKA.¹¹⁻¹⁶ Other unknown factors include long-term maintenance of postoperative alignment, the degree of correction achieved, the clinical outcome, and associated complications. To answer these questions, a retrospective evaluation of results with autologous bone graft in primary TKA was performed.

**Materials and Methods**

**Patient Group**

Outcomes of TKA with the FNK implant (Teijin Nakashima Medical Co, Okayama, Japan) were investigated in 2606 cases (4455 knees) treated at Nihon University School of Medicine, Itabashi Hospital, from July 1995 to December 2014. During this period, 72 patients (84 knees) underwent surgery that included autologous bone grafting for tibial bone defects. Of these cases, 60 patients (71 knees) had a follow-up period greater than 1 year, and of these, 68 knees in 57 cases treated with the FNK PS implant were evaluated. This patient series included 6 men (6 knees) and 54 women (65 knees). Of this group, 46 patients (55 knees) were diagnosed as having osteoarthritis and 14 patients (16 knees) were diagnosed as having rheumatoid arthritis. Average patient age was 71.2 years (range, 26-87 years), and average follow-up period was 6.6 years (range, 1.2-14.6 years). Seven surgeons, 2 of whom were authors (K.H., S.S.), contributed to this patient series. All patients provided informed consent for surgery preoperatively. Ethical approval for this study was obtained from the research review board of Nihon University School of Medicine, Itabashi Hospital. All patients had bone defects at the medial tibial surface assessed as peripheral defect types and as intact metaphyseal bone (type 1) according to the Anderson Orthopaedic Research Institute classification.¹⁷

**Surgical Procedure**

The proximal tibia was cut at 8 to 10 mm from the lateral tibial surface, as in standard arthroplasty surgery, and then autologous bone grafting was performed for patients who had bone defects of approximately one-sixth to one-third of the tibial surface area, greater than approximately 5 mm in depth. No more than 10 mm of the tibia was removed because removal of more than 10 mm would result in an unacceptably small tibial surface. In some cases, more severe bone defects, such as Charcot deformity, were observed, but severe joint instability required a more constrained implant (ie, constrained condylar knee type or hinged type). The type of prosthesis was selected preoperatively, and no changes were required. **Figure 1** shows the autologous bone grafting procedure that was used. A recipient bony site was cut obliquely with a bone saw without use of a guide tool. The removed tibial bone to be used for the surgical graft was then attached on the osteotomy side with the flattened recipient bony site, and it was confirmed that the graft was stable and attached without a gap. In 79 knees (86.8%), the graft was fixed with partially threaded 4.0×26-mm cannulated cancellous screws at the front and back sites of the bone graft. A single screw was used at each site, although 2 solid screws were used for the initial 9 knees (13.2%). The screws were inserted perpendicularly against the aspect of the tibial bone defect. The position of the keel to be set later was anticipated, and the 2 screws were inserted carefully. In 1 case, it was too difficult to insert 2 screws, so only 1 screw was used. As a result, the screws did not influence the movement of the knee joint and could be set without contacting the cross keel because of their short and narrow dimensions. Extra bone on surfaces of the graft other than the articular surface was removed to smooth the aspect of the tibia. Finally, it was confirmed that the graft had not moved, the screws had not contacted the keel or come out, and the graft had

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**Figure 1**: Intraoperative images showing an overview of the surgical technique (right knee). Bone defect after osteotomy of the tibia (A). Smoothing of the bone defect area with a bone saw (B). Fixation of the resected tibial bone to the bone defect with 2 cannulated cancellous screws (C). Cutting of the graft bone to smooth the surface of the tibia (D). Determination of the tibial tray position and insertion of a keel punch (E). Setting of a tibial implant with cement (F).
withstood the force of inserting the tibia tray. The bone graft was followed by a typical arthroplasty procedure, and all implants were fixed with cement.

Postoperative management was comparable to that for TKA without bone grafting. Briefly, intra-articular drainage was performed for 2 or 3 days after surgery, when patients began walking exercises. Sutures were removed 2 weeks postoperatively.

To assess bone union, the change in the standing femorotibial angle and other radiographic findings and knee radiographs, including the weight-bearing anteroposterior view with a fluoroscopic device, were obtained at each examination. The exact anteroposterior view for the tibial implant was observed with fluoroscopy. Two orthopedic surgeons who were members of the Japanese Orthopaedic Association evaluated the radiographs. For clinical evaluation, knee angle, range of motion, and knee and function scores were assessed according to the Knee Society clinical rating system. Complications were identified from the medical records. Patients underwent radiographic and clinical assessment at the study institution at 3 months and 1 year.

**Statistical Analysis**

For statistical analysis, the Wilcoxon test was used to examine the change in the femorotibial angle in the weight-bearing anteroposterior view on radiographic assessment and to assess changes in clinical parameters. All data were analyzed with StatView version 5.0 software (SAS Institute, Cary, North Carolina). P<.05 was considered significant.

**RESULTS**

### Bone Union and Radiographic Assessment

Bone union was evaluated on the final follow-up radiograph. The typical radiographic patterns for each group are shown in Figure 2. Ultimately, 97% (n=65) of patients achieved healing and 3% (n=2) did not. Evaluation was performed to determine whether osteosclerosis (sclerosis line) was present on the anteroposterior radiographs obtained 1 week postoperatively and at final follow-up. The sclerosis line was seen around the border between graft bone and the bone bed, and it was found on the side of the bone bed. The sclerosis line was observed in 21 knees (31.3%) 1 week postoperatively, and in most cases it was no longer apparent at final follow-up (Table 1). In 17 cases (25.4%), atrophy was observed at the medial proximal tibia, including the bone graft. In addition, a radiolucent line 2 mm or less in width was recorded in 6 cases (9.0%). Further, resorption within part or all of the bone graft was seen in 4 knees (6.0%).

Additionally, the standing femorotibial angle was measured preoperatively, 1 week postoperatively, and at final follow-up (Figure 3). The femorotibial angle was significantly reduced 1 week postoperatively compared with preoperatively. In addition, the change between 1 week postoperatively and final follow-up was less than 2°, which is within an acceptable error range for assessing radiographs. No local complications, such as backout of a screw or movement or collapse of the bone graft, occurred.

**Clinical Outcomes**

Clinical evaluation was performed by measuring knee angle, range of motion, and knee and function scores. At final follow-up, significant improvement of extension and flexion of the knee angle was noted compared with preoperative findings.

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**Table 1**

<table>
<thead>
<tr>
<th>Finding</th>
<th>No. of Cases</th>
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<tbody>
<tr>
<td>Sclerosis line (+)</td>
<td>21 (31.3%)</td>
</tr>
<tr>
<td>Observed</td>
<td>2 (9.5%)</td>
</tr>
<tr>
<td>Not observed</td>
<td>19 (90.5%)</td>
</tr>
</tbody>
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“Observed” and “not observed” indicate whether the sclerosis line could be seen on the radiograph obtained at final follow-up.
Knee and function scores also showed significant improvement (Table 2).

Complications
One patient was admitted for a deep infection 6 months after surgery. This patient had all implants and screws removed, and irrigation and debridement were performed. The graft bone was not removed because complete union with the tibia had occurred. Revision TKA was not performed at the request of the patient, who had severe diabetes. Asymptomatic deep venous thrombosis was identified in 2 patients (3.5%). It was detected during blood vessel echo examination of the lower limbs because of a high D-dimer level. The patients were treated with anticoagulants, and pulmonary embolism did not occur. Two patients (4.4%) had knees with wound dehiscence that were irrigated and resutured. Figure 4 shows a typical case in this series.

Discussion
In this large series of 68 knees treated with the FNK PS cemented standard stem implant and autologous bone grafting of the medial tibial plateau with 2 screws, union was achieved in 97% of the knees at 6.6-year follow-up. In addition, knee alignment was maintained between 1 week postoperatively and final follow-up, with acceptable improvement of function and a low rate of complications.

Dorr et al11 first reported that 22 of 24 knees treated with bone grafting TKA achieved bone union, whereas 1 knee collapsed. This report included TKA procedures performed with allografts. Although Laskin12 reported only a 67% success rate, subsequent studies showed better results.13-16 In a study of 54 cases, all achieved bone union, but the length of the stem and the type of prosthesis varied between cases.19 Differences in implants can change the stress within the tibia and significantly affect the union between the graft and recipient bone.20

In the current study, atrophy of the medial tibia was observed in some cases at final follow-up. Most of these cases may be attributed to stress shielding, which occurs in TKA. Implants that include a stem induce stress shielding in the proximal tibia.21 In the current study, the keel of this implant may have acted as a stem to induce atrophic change, but this did not affect bone union. In addition, for many patients, the sclerosis line disappeared and bone union was achieved. Even in cases where cancellous bone was not partially exposed, bone union could still occur.

In most cases, the bone graft was rigidly fixed with cannulated cancellous screws. Although some reports have described wire fixation16 and screwless fixation,14...
in the current study, screws were used to achieve rigid initial fixation. The strength of this fixation can be tested under the mechanical forces associated with insertion of the implant keel. Grafts that remain rigid during this process are likely to remain strong subsequently. This graft rigidity also may help to maintain long-term alignment.

The current study reported 68 TKA procedures performed with autologous bone grafting. To the authors’ knowledge, this is the largest number of cases reported so far. Japanese patients traditionally have had varus knees compared with Western individuals, and the pattern of osteoarthritis in the Japanese population may be associated with more severe varus deformity. Further, the procedures that were assessed all used the same PS prosthesis type, which allowed more accurate evaluation of the extent of bone graft union.

In the current study, the indication for autologous bone grafting was a tibial bone defect area that was greater than one-sixth of the tibial articular surface, with a depth of at least 5 mm. Bone quality becomes less biomechanically sound with a cancellous composite below the proximal 5 mm of tibia. However, Cuckler suggested that implant instability occurs when more than 40% of the bone-implant interface is unsupported by host bone; therefore, in some of the current cases, bone grafting may not have been needed.

**Limitations**

In the current study, it is unknown how much load was placed on the graft. Although it has been reported that an autograft is indicated in primary TKA with defects of 10 mm or less, the authors routinely perform autologous bone grafting for larger defects if sufficient autograft bone is available. With larger defects, when the use of autograft was expected to be difficult, instability was overcome with the use of more constrained implants with stems, such as a hinged type. However, because the degree of instability could not be determined, the indication for each prosthesis may have been vague. Future studies are needed to examine the utility of implant types prospectively.

**CONCLUSION**

This study evaluated a consistent surgical approach in a large patient series. Excellent outcomes were obtained with autologous bone grafts to support the PS implant. These results should be taken into account when considering the use of metal blocks or megaprostheses that lack bioactivity.

**REFERENCES**
