Most osteoarthritis (OA) patients with severe varus deformity of the knee show uncontained bone defects in the medial proximal tibia. Generally, after bone cutting, uncontained bone defects that are less than 5 mm deep are filled with bone cement, 5–10-mm-deep defects are treated with bone grafting, and ≥ 10-mm-deep defects are treated using metal augmentation. Although treatment outcomes of metal augmentation for uncontained defects ≥ 10 mm deep have been reported, the use of additional metal augmentation increases medical costs, requires further bone cutting to include the cortical bone, which makes bone loss inevitable, and can make future revision surgery more complicated.
surgery difficult. In the meantime, an autogenous onlay bone graft method has been introduced for uncontained tibial bone defects over 5 mm. Ahmed et al.’s method\(^5\) has the disadvantage that it must be fixed with a Kirschner wire (K-wire) by additionally excising the defective bone to obtain a flat cancellous surface. Yoon et al.’s method\(^6\) has a drawback that it is necessary to obtain bone union between cortical bone and another cortical bone after K-wire fixation. If sufficient bone union could be achieved with autologous bone grafting, even for severe bone defects, this would provide the advantages of preserving and strengthening the bone stock while also reducing medical costs. There have been few reported studies on treatment with autologous bone grafts in the treatment of patients with uncontained tibial bone defects greater than 10 mm deep in the medial proximal tibia during primary total knee replacement (TKR). In addition, no treatment has been established for bone grafts for uncontained tibial bone defects. Hence, we conducted this prospective cohort study on the treatment of uncontained bone defects of the medial proximal tibia to investigate the utility of bone grafts for uncontained tibial bone defects at a depth of 10 mm or more.

### METHODS

We identified patients who underwent primary TKR performed by a single surgeon (JGC) after 2015. We conducted this study in compliance with the principles of the Declaration of Helsinki. The protocol of this study was reviewed and approved by the Institutional Review Board of Daejeon Sun Hospital (IRB No. DSH-인-20-01). Written informed consents were obtained. The inclusion criteria were as follows: (1) a ≥ 10-mm-deep uncontained bone defect after medial proximal tibial cutting, (2) treatment with a standard tibial stem with autologous oblique structural peg bone and cancellous chip bone graft, but no metal augmentation, and (3) a follow-up period of at least 1 year. Patients with valgus OA, rheumatoid arthritis, or traumatic arthritis, and patients who underwent revision TKR or knee replacement using a long stem or metal augmentation were excluded. Finally, 40 patients were enrolled and their medical records were reviewed. There were 8 male patients and 32 female patients. Their mean age was 76 years (standard deviation [SD], 8.3 years; range, 58–89 years), the mean follow-up duration was 24.6 months (SD, 22.2 months; range, 12–38 months), and the mean body mass index was 26 kg/m\(^2\) (SD, 4.2; range, 18–34 kg/m\(^2\)) (Table 1).

The surgical method is as follows: After tibial bone cutting up to a depth of 10 mm from the articular surface of the lateral tibial condyle, the tibial plate was placed on the cut surface, and a sterilized ruler was used to measure the height of the bone defect remaining on the medial tibial condyle. For treatment of the bone defect, after selection of the appropriate tibial insert size to fit the cut bone surface, the tibial plate was placed on the cut surface to determine the position to make a furrow. Then, a 3-mm-diameter burr was used to cut a diagonal slope medial to the tibial defect at an angle of approximately 40° medial to the tibial long axis until the cancellous bone was visible in the base of the furrow.

Finally, a curved furrow was made according to the size of the bone defect, with a width of 3–4 mm and a depth of 5–10 mm anteroposteriorly (Fig. 1A). Using the segments of the femur and tibia excised during surgery, peg bone and chip bone were made to match the shape of the furrow. After distal femur and proximal tibia cutting,
cartilage was removed from the remaining bones. Cartilage-removed bones were first trimmed to a rectangular square shape with 3–4 mm in thickness and ≥ 10 mm in length using a 3-mm burr and a bone cutter. Three or more peg bones having such a shape and size were made to fill the length of the tibial bone defect furrow. After making peg bone, the remaining bone was made of chip bone to prepare a bone graft. The cortical portion of the peg bone was placed in the medial part of the furrow and fixed diagonally at an angle of 40°. First, one segment of peg bone was inserted into the anterior and posterior parts of the furrow, and then the remaining segment of peg bone was pressed into the middle. Finally, the peg bone was cut to match the cut tibial surface, making a double cortical supporter in the tibial medial condyle (Fig. 1B). The remaining bone defect medial to the peg bone was treated by drilling and then filling with chip bone (Fig. 2A). In all cases, a standard tibial stem and full cemented fixation technique was used without metal augmentation. All operations were performed using a midline skin incision and midvastus approach. For radiologic assessment, the mechanical femorotibial angle was measured using weight-bearing anteroposterior radiographs. This angle was defined on the computer screen as the angle between the mechanical axes of the tibia and femur at the center of the knee and was measured using ViewRex PACS (Techheim Co., Seoul, Korea) (Fig. 3). The area of the tibial cut surface was measured using photographs in the cut plane and ImageJ (ver. 1.52; NIH, Bethesda, MD, USA), and the percentage of the area occupied by the bone defect was calculated in the axial plane (Fig. 2B and C). After tibial implantation using the full cemented technique, the height of the tibial defect is measured (Fig. 4). Postoperative rehabilitation was the same as that provided to patients who did not undergo bone grafting. From the next day after surgery, patients started quadriceps femoris strengthening exercises, and weight-bearing was allowed without restriction. The drainage catheter was removed on the second postoperative day, after which passive and active joint exercise was commenced.

The mechanical femorotibial angle was measured
and compared preoperatively and at final follow-up in order to check for successful correction and the extent of correction. The angle was measured once each by three residents of orthopedic surgery (CUK, UJ, JG), and the mean of these measurements was used. Prosthesis loosening was checked by looking for the presence of a radiolucent line ≥ 2 mm on anteroposterior and lateral radiologic images of the knee joint, and sinking of the prosthesis was also checked. Prosthesis loosening, sinking of the prosthesis, and bone union were assessed radiologically at approximately 4 weeks, 3 months, and 1 year postoperatively based on the preservation of the grafted trabecular bone and the presence of trabeculae crossing the graft margin (Fig. 5).

For clinical assessment, preoperative and final follow-up Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores were compared. Joint range of motion (ROM) was assessed preoperatively and at final follow-up and was defined as the angle from maximal extension to maximal flexion measured using a goniometer when the patient actively flexed the knee as far as possible.

A one-way analysis of variance test was used for statistical analysis of differences in measurements by the three examiners (CUK, UJ, JG) during radiologic assessment. To compare preoperative and final follow-up clinical and radiologic findings, paired-samples t-tests were performed, and a Pearson's correlation analysis was used to assess correlations between variables. IBM SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis, and statistical significance was defined as a p-value of less than 0.05.

**RESULTS**

The mean depth of the bone defects measured in the operating room was 10.9 mm (SD, 1.2 mm; range, 10.0–15.0 mm), and the mean ratio of the area occupied by the bone defect in the axial plane was 18.4% (SD, 3.4%; range, 16%–34%) (Table 1). The depth of the defect and the relative area in the axial plane showed a positive correlation ($r = 0.364$), but this was not statistically significant ($p = 0.115$).

The mean time taken for bone grafting was 12 minutes (range, 9–16 minutes), and the mean total surgery duration was 88 minutes (range, 69–92 minutes). The mean thickness of polyethylene bearing used was 10.7 mm (SD, 1.0 mm; range, 10–12 mm).

There were no statistically significant differences in the radiological measurements of the three different examiners (preoperative femorotibial angle, $p = 0.537$ and last follow-up femorotibial angle, $p = 0.243$). The mechanical femorotibial angle was corrected from a mean of 19.5° varus (SD, 5.3°; range, 11.2°–31.1°) preoperatively to 0.2° varus (SD, 2.0; range, 4.7° varus–2.5° valgus) postop-

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**Table 2. Radiological and Clinical Values before Surgery and at the Last Follow-up**

| Variable                  | Preoperative     | Last follow-up    | p-value |
|---------------------------|------------------|-------------------|---------|
| Femorotibial angle (°)    | 19.5 ± 5.3 varus (11.2–31.1 varus) | 0.2 ± 2.0 varus (4.7 varus–2.5 valgus) | 0.002   |
| Range of motion (°)       | 128.5 ± 14.6 (85–145) | 135.5 ± 6.9 (120–145) | 0.012   |
| WOMAC                     | 69.3 ± 14.5 (60–86)  | 5.0 ± 4.0 (1–9)    | 0.010   |

*Values are presented as mean ± standard deviation (range).
WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.*

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**Fig. 5.** Postoperative follow-up radiographs of a 68-year-old female patient. (A) Two months postoperatively. (B) Twelve months postoperatively. (C) Two years postoperatively. (D) Three years postoperatively.
eratively \((p = 0.002)\) (Table 2). At final follow-up, all cases showed bone union without complications such as infection, prosthesis loosening or sinking, and nonunion, and no patients underwent revision surgery.

The mean ROM improved significantly from 128.5° (SD, 14.6°; range, 85°–145°) preoperatively to 135.5° (SD, 6.9°; range, 120°–145°) postoperatively \((p = 0.012)\). WOMAC scores also showed a significant functional improvement, decreasing from 69.3 (SD, 14.5; range, 60–86) preoperatively to 5.0 (SD, 4.0; range, 1–9) postoperatively \((p = 0.010)\) (Table 2).

DISCUSSION

When performing TKR in patients with severe knee OA accompanied by genu varum, proper positioning and alignment of the tibial knee prosthesis are essential to achieve successful outcomes.\(^2\,9\) There are two types of bone defects in the proximal medial tibia. Contained defects are those showing preservation of the cortical rim, which can support the tibial prosthesis. On the other hand, uncontained defects are those with no cortical rim to support the prosthesis, and they are often observed in patients with severe varus deformity.\(^5\) In standard tibial knee prostheses, load sharing between the cement and bone occurs at the cortical rim, cancellous bone, and stem, with over half (53%–67%) of load sharing occurring at the cortical rim.\(^9\) Therefore, prosthesis stability is inevitably much poorer in areas without the cortical rim, and suitable treatment is crucial.

Treatments for bone defects can be broadly divided into bone cement filling, bone grafting, and metal augmentation.\(^2\) In the case of large defects, especially severe uncontained defects, complications are common, such as prosthesis loosening or postoperative knee deformities, so bone cement is insufficient to repair the defect site.\(^10\) Bone grafts can provide biological stability by reconstructing the lost bone tissue through union, thus offering the advantage of preparing the patient for future revision replacement surgery. As explained at the beginning of the paper, an autogenous onlay bone graft method has been introduced for uncontained tibial bone defects over 5 mm.\(^5\) Ahmed et al.’s method\(^5\) has the disadvantage that it must be fixed with K-wire by additionally excising the defective bone to obtain a flat cancellous surface. Yoon et al.’s method\(^6\) has a drawback that it is necessary to obtain bone union between cortical bone and another cortical bone after K-wire fixation. However, the authors’ method does not have the problem of a graft bone being pushed out due to pressure during tibial implantation even without screws or K-wire fixation. In addition, cancellous bone union can be obtained without additional bone resection, and double cortical support can be obtained in the medial condyle, which has the advantage of obtaining strong medial support of the tibial implant. Metal augmentation provides superior support compared to bone cement\(^11\) and provides biomechanical stability of the prosthesis for weight-bearing and joint movement.\(^12,13\) However, it is not possible to achieve anatomical reconstruction of the bone, extra bone cutting is unavoidable, and protrusion of the augment can cause pain.\(^14\) Moreover, the additional use of metal augments increases medical costs.

Generally, it is advised to use bone cement for uncontained bone defects of <5 mm, bone grafting for uncontained defects of 5–10 mm, and metal augmentation for uncontained defects of ≥10 mm.\(^2\) However, we obtained positive outcomes, without bone resorption or prosthesis loosening by performing oblique structural peg bone and cancellous chip bone grafting for uncontained bone defects ≥10 mm deep.

In the present study, union was achieved in all cases, and there was no infection, bone graft resorption, or prosthesis loosening until the final follow-up. Baek et al.\(^15\) reported that, for severe bone defects of ≥10 mm in primary TKR, autologous bone grafting could not provide sufficient stability, so a long stem was needed, and for uncontained bone defects in particular, fixation of the grafted bone was technically difficult. However, in the present study, we used standard tibial knee prostheses (stem length, 35 mm) rather than a long stem, and by using the simple method of packing the bone graft tightly into the furrow, we obtained bone union in all cases without prosthesis loosening. Even if there was an uncontained tibial defect of ≥10 mm, the mean relative area of the bone defect in the axial plane was 18.4%, meaning that there was relatively little stress on the grafted bone. Moreover, since stronger cortical bone was present in the medial proximal tibia, double cortical support could be made inferomedial to the tibial insert by further restoration of the cortical rim; therefore, we believe that sufficient stability could be achieved without metal augmentation, such as a long stem.

In a study analyzing tibial implants, stem morphology, and their effects, Scott and Biant\(^16\) reported that short 35–50-mm stems were universally used and produced satisfactory clinical outcomes and that this was correlated with a decrease in stress concentration. Tapered stems, in which the diameter decreases distally, contribute to prosthesis stability by reducing shear forces between the stem, cement, and bone.\(^17,18\) In addition, bone cement fills the aperture between the tibial knee prosthesis and the bone.
of the tibial plateau, resulting in more even stress dispersion and also reduction of micromotion, which helps with prosthesis stability.\textsuperscript{19,20} In summary, it is possible to achieve robust fixation and stability by using bone grafting to restore the cortical rim and create support for the medial proximal tibia and by using bone cement and a tibial prosthesis with a tapered stem of an appropriate length. We restored the cortical rim and made a suitable shape with the simple method of shaping the cut tibial surface and fitting trabecular bone tightly into an elliptical furrow. After the trabecular bone graft, a small amount of cancellous bone was harvested from the remaining bone, and this was used to fill in the remaining part of the defect, lateral to the trabecular bone. The tibial knee prosthesis used in this study was very short, with a stem length of 35 mm, and cement was used to fix the prosthesis. Because we used a short stem and restored the medial proximal tibia with autologous bone grafting, rather than metal augmentation, there could be concerns about poor prosthesis stability, but we did not observe nonunion of the graft or prosthesis loosening in any cases. Since this was a study of tibia with $\geq 10$-mm-deep uncontained bone defects, we cannot firmly conclude that short 35-mm stems will provide sufficient stability. If our method of oblique structural peg bone and cancellous chip bone grafting had not provided robust stability of the prosthesis, loosening could have occurred. However, even though we used 35-mm standard prostheses with a short stem in all cases, all patients showed bone union without prosthesis loosening. Therefore, in patients with uncontained tibial defects of $\geq 10$ mm, we believe that sufficient stability of 35-mm standard prostheses can be achieved using our bone grafting method, even in the absence of a long stem. In addition, all patients showed bone union without prosthesis loosening, even though full weight-bearing gait was allowed from the next day after surgery and we did not place any restrictions on joint ROM. This is further evidence that this method provides sufficient stability for $\geq 10$-mm-deep uncontained tibial defects, even when using a standard prosthesis. We used a simple method of inserting a long rectangular shaped support bone into the furrow of a bone defect and filling the defect using the remaining bone after the implantation of the support bone. The bone graft method described in this paper can be a useful technique for orthopedic surgeons; it has a simple and short learning curve and thus can be easily applied in the operating room to reinforce bone defects during primary TKR. This study has several limitations. There were few cases, the 1-year follow-up was short to confirm the patient’s progress. We did not compare the outcomes with those of other treatment methods, and we did not consider bone density in the proximal tibia. In addition, we concluded that the prosthesis was sufficiently stable based on the fact that all patients showed union without loosening at follow-up, but we did not measure objective indices of stability. In future research, it will be necessary to improve upon these limitations by performing biomechanical studies using cadavers and by comparing the outcomes with those of other methods.

In primary TKR for patients with an uncontained tibial defect, which is $\geq 10$ mm deep and occupies < 30\% of the total area in the axial plane, oblique structural peg bone and cancellous chip bone grafting can be a useful treatment method for providing satisfactory radiologic and clinical outcomes when using a standard tibial knee prosthesis with a short 35-mm stem, even without additional metal augmentation.

**CONFLICT OF INTEREST**

No potential conflict of interest relevant to this article was reported.

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