Anterior cervical fusion is a widely accepted treatment for cervical degenerative diseases, including spondylotic myelopathy and ossification of the posterior longitudinal ligament (OPLL). As a common practice, autologous bone harvested from the iliac crest or fibula is used for anterior cervical fusion. However, significant complications occur at the donor site following the harvest of iliac crest bone, including donor-site pain, hematoma, infection, fracture of the ilium, sensory disturbances, and cosmetic disabilities. A high incidence of complications has also been reported for the harvesting of autologous fibulas. Due to the morbidity associated with autograft harvesting, alternative graft materials have been investigated.

Hydroxyapatite (HA) is a highly crystalline form of calcium phosphate and a biocompatible ceramic that is produced by a high-temperature reaction. The nominal composition of this mixture is $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ with a calcium-to-phosphate atomic ratio of 1.67. The unique
property of this material is its chemical similarity to the mineralized phase of the bone; this similarity accounts for its osteoconductive potential and excellent biocompatibility.6

The usefulness of synthetic HA in anterior cervical disectomy and fusion (ACDF) has been reported previously.7 For the treatment of patients with OPLL, corpectomy is often necessary for sufficient decompression.8 Anterior cervical corpectomy and fusion (ACCF) needs removal of vertebrae, and thus requires much greater graft height when compared with ACDF. This can cause a higher rate of graft-related complications, such as nonunion or graft dislodgement. However, the efficacy and safety of the use of HA in ACCF as a strut graft has not been well investigated.

In the current study, the authors investigated the efficacy of the use of a porous HA block in ACCF. To enhance fusion, the authors used HA blocks with local cancellous bone chips harvested from the vertebrae. The outcomes of ACCF using HA were compared with those of a historical control group of OPLL patients who underwent ACCF using an autologous fibula bone graft (FBG).

**Materials and Methods**

This study was approved by an institutional ethics committee. From May 2006 to March 2013, twenty-five patients with OPLL (18 men, 7 women; average age, 55.8 years) underwent ACCF using HA blocks (HA group) at the authors’ institution after providing the appropriate informed consent.

The authors used HA blocks for 1- and 2-level corpectomies, and patients who required corpectomies at 3 or more continuous vertebrae were excluded because of the size limitation of the HA blocks; 6 patients needed fibula bone grafting during this period and were not included in this study. When the OPLL was located at C3-C6, a 2-level ACCF was performed (corpectomies of C4 and 5). Hybrid procedures were performed based on the location of the OPLL when possible9 (eg, 1-level ACCF [C3-C5]/1-level ACDF [C5/C6] to fuse from C3 to C6).

The authors performed 1-level ACCF in 9 cases, 1-level ACCF/1-level ACDF in 7 cases, 1-level ACCF/2-level ACDF in 1 case, 2-level ACCF in 4 cases, 2-level ACCF/1-level ACDF in 3 cases, and 2-level ACCF/2-level ACDF in 1 case. A hybrid procedure was considered if the OPLL is segmental or mixed-type and if there is a vertebrae where the spinal cord was not compressed by OPLL within the operated levels. However, the final decision for making for a larger corpectomy or hybrid construction was at the surgeon’s discretion.

The HA blocks used had open-pore structures. The morphology of the HA was observed by scanning electron microscopy. The samples of HA were mounted on a scanning electron microscope pin stub mount and sputter-coated with gold. A Hitachi S-2600H scanning electron microscope (Hitachi High-Technologies, Tokyo, Japan) was used to acquire images (Figure 1). The authors used HA with 40% porosity for the 1-level ACCFs and 15% porosity for the 2-level ACCFs. The compressive strength of the 40% porous HA was 65 MPa, and that of the 15% porous HA was 200 MPa. The manufactured HA blocks (Hoya Biomaterial, Tokyo, Japan) ranged from 21 to 42 mm in height and had widths and depths of 15 and 12 mm, respectively. The HA blocks had notches on their upper and lower aspects (Figure 2). For the sites of the disectomies in the ACDFs with the hybrid procedure, a porous/dense composite HA was used.7

**Surgical Procedures**

The surgeries were performed by 5 attending spine surgeons (T. Yoshii, K.S., H.I., T.K., A.O.) at a single institution. The anterior OPLL floating technique described by Matsuoka et al10 was used. A standard Smith–Robinson approach to the cervical spine was used.1 After confirmation and exposure of the appropriate vertebral levels, corpectomy was performed by removing the disks and vertebral bodies. Next, the OPLL was gradually ground thin using a diamond bar and allowed to float anteriorly from the spinal canal without removal.

After decompression, the HA blocks were inserted into the decompressed spine. Subsequently, autologous cancellous bone chips from the vertebral bodies on which the authors had performed the corpectomies were grafted beside the HA block (between the HA block and the Luschka joints) to further enhance the fusion.11 After the grafting of the HA with the cancellous bone chips, anterior plating (Atlantis Plate or Venture; Medtronic Sofamor Danek, Memphis, Tennessee) was performed (Figure 2).

Postoperatively, the cervical spine was immobilized using a neck collar for 3 months. The patients underwent follow-up examinations at 3, 6, and 12 months after surgery and yearly thereafter. All patients were followed for a minimum of 2 years.
Clinical Outcomes

Neurological functions were evaluated using the Japanese Orthopaedics Association (JOA) scoring and associated recovery rate. In addition, the operation time, intraoperative bleeding, and postoperative complications were evaluated. In the postoperative follow-up, the authors evaluated neurological status and complications, including general, neurological, and graft-related complications, using a standardized datasheet.

Radiographic Outcomes

Plain anteroposterior and lateral cervical spine radiographs were obtained pre- and postoperatively and at each follow-up examination. The Cobb angle of the segment subjected to the surgery was measured. The extent of the cervical sagittal lordosis was evaluated between C2 and C7. The radiographic fusion criteria were graded as follows: grade 1 fusion was defined by the absence of a radiolucent zone between the HA and the end plates on the reconstructed computed tomography scans and the lack of translation or angulation changes in the lateral flexion-extension radiographs; and grade 2 fusion was defined by the recognition of bone bridging around the HA on the sagittal or coronal computed tomography scans in addition to the criteria for grade 1 fusion (Figure 2).

Clinical and radiological outcomes of ACCFs using the HA blocks with cancellous chips (HA group) were compared with those of a historical control group of consecutive 25 patients (19 men, 6 women; average age, 60.1 years) who underwent ACCF using autologous fibula bone graft anterior plating (FBG group) at the authors’ institution from 2001 to 2006. The authors performed the hybrid procedure (ACCF+ACDF) in 5 patients in the FBG group, whereas 12 patients in the HA group received hybrid fusion. The statistical analyses were performed using unpaired t tests for continuous variables and chi-square tests for categorical data. The significance level was set at P<.05.

RESULTS

Patients’ demographic data for the HA and FBG groups were similar. No significant differences were found in age, sex, OPLL canal-occupying ratio, number of treated levels during surgery, preoperative cervical alignment, or preoperative neurological function based on the JOA score (Table 1). A significant difference was found between the 2 groups in the follow-up length.

Neurological scores improved sufficiently postoperatively in both groups (Table 2). No significant difference was found between the 2 groups in the postoperative recovery rate based on the JOA score (65.2% in the HA group and 64.8% in the FBG group). No differences were found in the operation time between the 2 groups; however, intraoperative blood loss in the HA group was significantly lower (P<.05) than that in the FBG group (Table 2).
The ACCF with HA procedure achieved successful fusion in all cases (Figure 3), including grade 1 in 3 (12.0%) of 25 cases and grade 2 in 22 (88.0%) of 25 cases (Table 3). All of the segments in which ACDF was performed exhibited grade 2 fusion. All of the grade 1 fusions were observed in corpectomy sites. There were no cases of nonunion in the HA group. In the FBG group, 24 of 25 (96.0%) cases achieved radiographic fusion, whereas 1 (4.0%) case of nonunion was observed. The segmental lordosis at the fused segments was enhanced postoperatively in both the HA and FBG groups but slightly decreased at the 2-year follow-up. However, the postoperative improvements in the lordotic angles were not significantly different between the 2 groups. The cervical alignments at C2-C7 were enhanced postoperatively and preserved at the 2-year follow-up in both groups (Figure 4).

The incidences of postoperative approach-related complications were similar in the HA (dysphagia, 3; upper airway obstruction, 1; hematoma, 1) and FBG groups (dysphagia, 2; hematoma, 1). The incidences of graft dislodgement were similar in the HA (n=2, 8.0%) and FBG groups (n=2, 8.0%). However, graft subsidence was more frequently observed in the FBG group (n=6, 24.0%) than in the HA group (n=2, 8.0%). Notably, 9 (36.0%) of 25 patients complained of prolonged pain or sensory disturbances at the donor site in the FBG group. Minor cracks of the graft were found at the corners of the implants in 2 (8.0%) of the HA blocks on postoperative computed tomography scans that were acquired immediately postoperatively. However, these cracks did not affect the stabilities or alignments of the operated segments, and both of these cases eventually achieved radiographic fusion.

**DISCUSSION**

The goals of anterior decompression with fusion include the removal of neural compression, the restoration of stability, and the restoration or maintenance of spinal alignment. An autologous graft harvested from the ilium or fibula can provide satisfactory clinical results in terms of achieving these goals. However, such procedures can result in a high incidence of donor-site complications, such as prolonged pain, hematoma, and sensory disturbances. Fibula allografts are considered to be an excellent option, but the union rate is not as high as with the use of autograft. Furthermore, this allograft is not commercially available in some Asian countries, including Japan, and thus is rarely used in anterior fusion. Other options include titanium or polyetheretherketone cages, polymethylmethacrylate, and osteoconductive ceramic spacers such as HA.

In this study, the authors investigated the usefulness of ACCF using HA for the treatment of patients with OPLL. Hydroxyapatite is a highly crystalline form of calcium phosphate and a biocompatible ceramic produced by a high-temperature reaction. Since the synthetic techniques for producing HA were established, synthetic HA has been used clinically for bone defects and spinal fusion. In anterior cervical fusions, HA has been primarily used for ACDF and rarely used for multilevel ACCFs, which are often required in the treatment of patients with...
OPLL. Because the sizes of the defects and the lengths of the required fusions at the corpectomy sites in ACCF are much greater than those at the sites of discectomies in ACDF, successful fusion with HA is considered to be more challenging in ACCF than in ACDF. Therefore, the authorsgrafted local autologous bone chips harvested from the vertebral bodies on the sides of the material to enhance bony fusion.

Generally, a high porosity of HA exposes a large surface area to the host tissue. As a result, it can provide a better scaffold for precursor cells and thus promote biological changes, such as cellular attachment and bone formation. However, the porous structure is associated with lower mechanical properties and less initial strength after implantation. In this study, the authors used a highly osteoconductive HA graft with a 40% porosity for a 1-level corpectomy and biomechanically strong HA with a 15% porosity for 2-level corpectomies.

In the postoperative radiological examinations, asymptomatic nonunion was observed in 1 patient in the FBG group. However, fusion was observed in all of the patients in the HA group, even in the cases using HA with 15% porosity. Notably, nearly 90% of the patients exhibited grade 2 solid fusion in the HA group. Only 3 patients exhibited grade 1 fusion, which lacked bony fusion around the HA. However, no segmental motion at the fusion site and no related symptoms were observed in these 3 patients. Based on these results, HA with local bone grafting at the site of corpectomy is sufficiently useful and effective to stabilize the decompressed segments.

Despite the excellent osteoconductive ability of HA, there are concerns about the mechanical properties of porous HA. Zdeblick et al. reported a high collapse rate of coralline-derived porous HA in a dog interbody fusion model. McConnell et al. also reported higher rates of graft fragmentation in porous HA compared with autologous iliac bone. However, the synthetic HA used in the current study has a much greater mechanical strength than coralline-derived HAs (compressive strength <10 MPa). The HA with a 40% porosity had a compressive strength of 65 MPa and that of the 15% porous HA was 240 MPa.

Several studies have investigated the biomechanical strength required for ACDF and reported that the normal compressive load on the graft ranges from 12 to 90 N. Therefore, the material used in the current study is thought to exhibit sufficient mechanical strength for load bearing. Nevertheless, there are still potential risks for material collapse due to repetitive mechanical stress on the graft, as previously reported. Because an anterior plating system can reduce the mechanical stress on the graft in ACDF, the current authors used anterior plates to minimize the risk of graft failure. Consequently, there were no cases of major fragmentation or collapse of the HA that required revision surgery.

In the current study, the comparisons of the composite HA and FBG as graft materials for ACCF showed no significant differences in terms of neurological recovery, fusion rates, or the sagittal alignment of the operated segments and cervical spine. The incidences of approach-related complications were similar in the HA and FBG groups. However, in the HA group, the intraoperative blood loss was less than that in the FBG group. Furthermore, donor-site complications were observed in 36.0% of the patients in the FBG group.

Based on these results, ACCF using HA with a local bone graft is considered to be a less invasive method with less intraoperative bleeding and no donor-site complications. The incidences of graft dislodgement were similar, but graft subsidence was more frequently observed in the FBG group. Because the upper and lower surface areas of the fibula grafts that contacted the host bone were smaller than those of the HA and because the cortical edge of the fibula is too solid, the use of fibula grafts may be more likely to result in graft subsidence.

There are some limitations to this study. This study compared HA and autologous fibulas as graft materials in ACCF in a retrospective manner with relatively small sample size. This comparison was not based on a randomized controlled clinical trial. There were cases of ACCF alone and ACCF-ACDF combinations (hybrid procedures) depending on the location of the OPLL. The authors tended to choose the hybrid procedures more often in the HA group than in the FBG group because of the size limitation of HA, which can be a potential bias in comparison of the 2 groups.

The authors did not compare HA with other substitutes, such as titanium cages or fibula allografts. The HA blocks...
that were used can be available for 1- or 2-level corpectomies, but a fibula graft still needs to be used for 3 continuous corpectomies. Despite these limitations, this is the first study comparing the HA grafts and autologous fibula bone grafts for use in ACCF. The current study demonstrated that the use of HA combined with local cancellous chips is a safe and effective alternative procedure to conventional autologous fibula grafts for ACCF for the treatment of OPLL.

CONCLUSION
Anterior cervical corpectomy and fusion using HA is a safe and efficacious method for the treatment of patients with OPLL. This method seems promising as an alternative to conventional ACCF using autologous fibula bone grafting.

REFERENCES