INTRODUCTION

Spinal fusion is the most frequently performed surgery to treat spinal disorders. The ultimate aim of spinal fusion surgery is to achieve complete fusion at the index level. Non-union is a critical complication of this surgery, with a prevalence of approximately 10% to 40%\(^\text{11}\).

Equipment such as pedicle screws, rods, wires, and cages have been used to achieve fusion of unstable spinal segments. However, previous studies have reported that 10% to 15% of all such cases showed pseudoarthrosis\(^\text{11}\). Bone grafting is another strategy to augment spinal fusion. Autologous iliac bone graft is the most commonly used bone graft and is regarded as the gold standard in bone grafting\(^\text{21}\). This method is preferred due to successful fusion rate and low risk of disease transmission\(^\text{11}\).

However, this procedure is sometimes associated with unexpected morbidities such as fractures, hernia, ureteral injury, pelvic instability, infection, and chronic donor site pain\(^\text{21}\). In addition, there are several limitations aside from its morbidity including separate incision for harvesting, increased surgical time, and limited or insufficient amount of graft.

Demineralized bone matrix (DBM), which is produced from human allograft tissue, is an alternative to an autograft. DBM consists of bone morphogenic proteins (BMP), collagen, and other synergistic proteins such as transforming growth factor and insulin-like growth factor\(^\text{21}\). Therefore, DBM has osteoin-
ductive and osteoconductive characteristics that allow it to be used as a graft extender or substitute. Hydroxyapatite is also frequently used as a graft extender or substitute because it has osteoinductive characteristics and augmentation of the osteoconductive features of an autograft. According to prior investigations, hydroxyapatite shows nearly equivalent fusion results to autografts.

Many trials have been conducted on the surgical outcomes of spinal fusion surgery using allografts. Reportedly, in many trials, the fusion rates of DBM were similar to those of autografts. Cammisa et al. reported a 52% fusion rate in Grafton DBM in lumbar spinal surgery, which is comparable to 54% when using autografts. An et al. reported a 54% fusion rate in anterior cervical fusion surgery using Grafton DBM and 74% when using autografts. However, many of these studies evaluated the fusion status using plain radiographs.

Hydroxyapatite DBM is a newly designed material, the fusion rate of which has not yet been reported. In this study, we investigated and compared the fusion rates of hydroxyapatite DBM and autografts using CT scans at 12 months after operation. In addition, we measured clinical scores to evaluate the impact of fusion on clinical outcomes.

MATERIALS AND METHODS

Patient population

From January 2013 to April 2014, 98 patients diagnosed with lumbar stenosis underwent lumbar interbody fusion surgery using hydroxyapatite DBM (Bonfuse™, CG Bio, Seoul, Korea) in Severance Hospital. This study was approved by the institutional review boards at Severance Hospital. We excluded patients with a history of infection, trauma, spinal tumor, spondylolytic spondylolisthesis, or previous spinal surgery. Patients using steroid medications or who had metabolic bone disease such as Paget's disease or renal osteodystrophy were also excluded. Ultimately, 65 patients (75 interbody levels) were eligible for this study and underwent postoperative CT scans for 12 months (the HA-DBM group). Another 65 patients (74 interbody levels) who underwent lumbar interbody fusion surgery using autograft during the same period were enrolled for comparison (the Autograft group). The subjects in the Autograft group were of similar age, sex, bone mineral density (BMD), and body mass index (BMI) and also underwent postoperative CT scans for 12 months. Therefore, a total of 130 patients (149 interbody levels) were evaluated using CT scans.

Operative technique

One fusion technique (posterior lumbar interbody fusion, (PLIF) anterior lumbar interbody fusion (ALIF) or transforaminal lumbar interbody fusion (TLIF)] was performed in each patient. We performed pedicle screw fixation on each PLIF and TLIF case. All of TLIF cases were open TLIF and minimal invasive TLIF was not conducted. The DBM volume was determined by the size of the cage. Each surgical technique requires an appropriate cage in terms of height, length, angle, and shape. Therefore, we used the optimal volume of DBM allograft in each case. When using autologous bone graft, the extracted lamina and spinous process were cut into small pieces and used to fill the cage.

Assessment of fusion state

Fusion grade was assessed using coronal or sagittal reconstruction images of lumbar CT scans. All CT scans were performed at one year after surgery. The fusion grade was classified from Grade I to IV. We classified Grade I (cortical union of the graft material and central trabecular continuity) and Grade II (cortical union of the structural graft material with partial trabecular incorporation) as "Fused" and Grade III (superior or inferior cortical non-union of the central graft material with partial trabecular discontinuity centrally) and Grade IV (both superior and inferior cortical non-union with a complete lack of central trabecular continuity) as "Not-fused" (Fig. 1).

We also measured clinical outcomes including visual analogue scale (VAS) score, Oswestry Disability Index (ODI), and Short Form Health Survey (SF-36) score in order to compare the surgical outcomes between the two groups.

Measurement validation

To assess the reliability of the measurements, two examiners measured the fusion status twice at a one-week interval for each of the 130 cases. In cases of discrepancies, the fusion grade was determined through debate in conferences. Inter-examiner and intra-examiner ICC and 95% confidence interval (95% CI) were assessed. Inter-examiner reliability was assessed using the intra-class correlation coefficient (ICC) of data obtained for the measurement of fusion status between both examiners. Intra-examiner reliability was assessed between the first and second measurements for each individual examiner.

Statistical analysis

The measured variables were analyzed using independent t-test analysis and chi-square analysis. We applied the paired t-
RESULTS

Mean age was not significantly different between the groups.

Table 1. Group demographics

|                     | HA-DBM group, mean±SD | Autograft group, mean±SD | p-value |
|---------------------|-----------------------|--------------------------|---------|
| Age (years)         | 63.6±10.19            | 62.5±10.04               | 0.528   |
| Sex (M : F)         | 16 : 46               | 20 : 45                  | 0.848*  |
| BMD (T-score)       | -1.91±1.06            | -2.05±1.27               | 0.527   |
| BMI (kg/m²)         | 27.39±3.03            | 25.5±3.75                | 0.610   |

Indepente t-test was performed. *Chi-square tests were performed. HA-DBM: hydroxyapatite demineralized bone matrix allograft, BMD: bone mineral density, BMI: body mass index, PLIF: posterior lumbar interbody fusion, ALIF: anterior lumbar interbody fusion, TLIF: translaminar lumbar interbody fusion, SD: standard deviation

Table 2. Comparison of fusion rates at postoperative 12 months

|                     | Fused | Not fused | p-value |
|---------------------|-------|-----------|---------|
| HA-DBM group        | 39    | 46        |         |
| Autograft group     | 36    | 28        |         |
| Fusion rate (%)     | 52    | 62.2      | 0.210*  |

*Chi-square tests were performed to analyze the fusion rate. Fusion rate=fused levels/(fused+not fused levels) ×100. HA-DBM: hydroxyapatite demineralized bone matrix

Table 3. Comparison of demographics in terms of fusion

|                     | HA-DBM group | Autograft group | p-value |
|---------------------|--------------|-----------------|---------|
| Age (years)         | Fused, mean±SD | Not fused, mean±SD | 0.027   |
|                     | 61.24±9.45   | 66.86±10.42     |         |
| Sex (M : F)         | 9 : 28       | 10 : 18         | 0.317*  |
| BMD (T-score)       | -1.63±0.90   | -2.29±1.16      | 0.015   |
| BMI (kg/m²)         | 23.7±3.22    | 24.04±2.80      | 0.675   |

Indepente t-test was performed. *Chi-square tests were performed. HA-DBM: hydroxyapatite demineralized bone matrix, BMD: body mass index, BMI: bone mineral density

Table 4. Comparison of clinical outcomes between groups

|                     | HA-DBM group | Autograft group | p-value |
|---------------------|--------------|-----------------|---------|
| VAS                 | Fused, mean±SD | Not fused, mean±SD | 0.004   |
|                     | 5.31±2.52    | 2.93±2.17       |         |
|                     | 6.16±2.36    | 3.45±2.56       | 0.008   |
|                     | 5.01±3.21    | 2.36±2.17       | 0.012   |
| ODI                 | 40.8±15.5    | 22.3±19.3       | 0.002   |
|                     | 48.6±21.7    | 29.7±16.3       | 0.005   |
|                     | 41.2±14.3    | 28.6±20.3       | 0.030   |
|                     | 53.8±16.5    | 56.7±19.9       | 0.528   |
|                     | 54.5±6.2     | 45.9±6.9        | 0.885   |

Paired t-test was performed to analyze the clinical outcome score. VAS: visual analogue scale, ODI: Oswestry Disability Index, PCS: physical component score, MCS: mental component score

In the HA-DBM group, 39 interbody levels were “Fused” and 36 interbody levels were “Not-fused,” resulting in a 52% fusion rate. In the Autograft group, 49 interbody levels were “Fused” and 28 levels were “Not-fused,” resulting in a 62.2% fusion rate. Fusion rate was not statistically significantly different between the two groups (p=0.21) (Table 2).

Next, we compared the “Fused” subgroup with the “Not-fused” subgroup in each group. In the HA-DBM group, the “Fused” subgroup showed significantly lower mean age than the “Not-fused” subgroup (“Fused” subgroup 61.24±9.45 vs. “Not-fused” subgroup 66.86±10.42, p=0.027). In addition, the BMD was significantly lower in the “Not-fused” subgroup (“Fused” subgroup 61.24±9.45 vs. “Not-fused” subgroup -2.29±1.16, p=0.015). Conversely, there were no significant differences between the “Fused” and the “Not-fused” subgroups in the Autograft group (Table 3).

VAS and ODI were improved significantly in the HA-DBM group regardless of fusion (preoperative 5.3, postoperative 2.9; preoperative 40.8, postoperative 48.6 in “Fused”; preoperative 6.2, postoperative 3.4; preoperative 48.6, postoperative 29.7 in “Not-fused”). In the Autograft group, VAS and ODI showed significant improvement in the “Fused” subgroup (preoperative 5.6, postoperative 2.6 and preoperative 41.2, postoperative 28.6, respectively) but not in the “Not-fused” subgroup (p=0.192). The
SF-36 score, which was composed of a physical component score (PCS) and a mental component score (MCS), was not significantly different between the groups regardless of fusion (Table 4).

DISCUSSION

Spinal fusion surgery is the treatment of choice in various spinal disorders. Pseudoarthrosis has remained a challenging problem with this surgery; thus, bone grafts are used to alleviate this problem. Due to the limitations of iliac bone graft, local corticocancellous bone chip acquired from laminectomy is frequently used. The fusion results whether using local bone chip or iliac bone graft are equivalent. However, limited volume might result from this conventional method and can be unfavorable in some cases with a low proportion of cancellous bone in the local graft. As an alternative, DBM products were developed to use as a graft expander or substitute. The fusion rates of previous commercial DBM products are similar to those of autograft.

The fusion achieved when using DBM and hydroxyapatite mixtures have been evaluated in several trials. According to Lee et al., the combined use of DBM and hydroxyapatite indicated osteoinductive differentiation in vitro. They showed that the mixture has osteoinductive characteristics by performing in vitro studies. In addition, many clinical trials have reported successful fusion results with hydroxyapatite DBM. Osteoinductivity and osteoconductivity were present in the hybrid compound, indicating that hydroxyapatite with DBM can be an adjunct to autografts.

Our results showed a lower fusion rate in the hydroxyapatite HA-DBM group than the Autograft group, although the difference was not statistically significant. Many previous studies have reported lower fusion rates of DBM allograft than autograft, but also without statistical significance. Although the fusion rates of DBM allograft were lower than those of autograft, the surgical outcomes of DBM allograft were not inferior to those of autograft, suggesting that DBM allograft is a good alternative to autograft. The overall fusion rates in previous studies were higher than those in the present study. Fusion rates in previous articles regarding allograft material vary widely from 60% to 98%. We believe these differences originated from the different methods used for fusion assessment. Most previous studies assessed fusion status using plain radiographs; however, CT scans are more reliable to evaluate the exact fusion status. Therefore, the fusion rate assessed using CT scans is more accurate and more precisely represents the fusion rate.

Unlike the Autograft group, the fusion rate in the HA-DBM group was affected by age and BMD. Okuyama et al. reported that pseudoarthrosis was more frequent in patients with low BMD. In addition, Inoue et al. reported that bone formation is decreased in older patients due to a smaller number of stromal cells in bone marrow. In addition, in animal studies, bone healing was shown to require a longer time in older age. Low BMD and older age are risk factors for non-union. However, these factors affected only the HA-DBM group in our study. This finding suggests that hydroxyapatite DBM is more susceptible to age and BMD than is autograft. Consequently, when considering spinal fusion surgery with DBM products, older age and low BMD should be taken into account as risk factors.

We measured clinical scores by evaluating VAS, ODI, and SF-36 (PCS and MCS) scores. The VAS and ODI score after surgery were improved in both groups. These results are similar to other previous studies. The improvements were statistically significant except in the “Not-fused” subgroup of the Autograft group. This result might be due to the small number of enrolled patients. In addition, the changes in SF-36 score were not significant after surgery. We also believe that 12 months is a relatively short period in which to achieve complete fusion status, and bone formation and tissue healing might be ongoing at fusion sites.

This study had several limitations. First, CT scans were performed 12 months after surgery. Considering that a two-year follow-up has been proposed as the time required to definitively evaluate the solidity and stability of spine fusion, 12 months might be too short to precisely evaluate fusion status and can lead to underestimation of fusion results. The other limitation was that we did not consider other factors that might affect fusion status. Diabetes mellitus is known to reduce the fusion rate in spinal surgery. Diabetes delays the postoperative bone healing process stimulated by enhanced tumor necrosis factor α to reduce proliferation and promote necrosis of mesenchymal stem cells. Additionally, local insulin concentration can affect the fusion results by modifying the level of insulin like growth factor-1 at the fusion site. Smoking also affects bone formation. An et al. and Anderson et al. reported that nicotine disturbs the microcirculation of fusion beds and affects the fusion rate.

CONCLUSION

This study demonstrated that the fusion rates of a hydroxyapatite HA-DBM group and Autograft group were not significantly different. In addition, the clinical outcomes were similar between the groups. Therefore, the hydroxyapatite DBM allograft can be used as an alternative to conventional autologous bone grafts but should be carefully considered in older or low-BMD patients.

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