Original Article
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Could the Type of Allograft Used for Anterior Cervical Discectomy and Fusion Affect Surgical Outcome? A Comparison Between Cortical Ring Allograft and Cortico-Cancellous Allograft

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Background: Allograft is predominantly used interbody spacers for anterior cervical discectomy and fusion (ACDF). The cortico-cancellous allograft has weaker mechanical strength as it is an artificial composite of the cancellous and cortical parts. Additionally, whether utilizing a firmer allograft, such as the cortical ring, leads to better outcomes is unclear. Therefore, we aimed to compare the surgical outcomes of cortical ring and cortico-cancellous allografts in ACDF.

Methods: Patients who underwent ACDF using allograft and were followed up for > 1 year were retrospectively reviewed. Patient characteristics, including fusion rates (assessed by interspinous motion [ISM], intra-graft bone bridging, and extra-graft bone bridging), subsidence, allograft complications (e.g., allograft fracture and resorption), and patient-reported outcome measures (neck pain visual analog scale [VAS], arm pain VAS, and neck disability index), were assessed. Patients were divided into 2 groups based on the allograft used: cortical ring and cortico-cancellous allograft groups. Subgroup analysis was subsequently conducted in single- and multi-level operation groups.

Results: A total of 227 patients were included. Of them, 134 (59.0%) and 93 (41.0%) underwent ACDF using cortical ring and cortico-cancellous allograft, respectively. In single-level operations, the cortico-cancellous allograft significantly frequented allograft resorption (24 / 66, 36.4%) than the cortical ring allograft (1 / 28, 3.7%) ($p = 0.001$). The cortico-cancellous allograft group demonstrated significantly greater subsidence. However, the fusion rates did not significantly differ between the 2 groups. In multi-level operations, the cortico-cancellous allograft (5 / 27, 18.5%) resulted in a significantly higher fracture rate than the cortical ring allograft (5 / 105, 4.7%) ($p = 0.030$). The fusion rate at 1-year postoperative assessed using ISM (63.2% vs. 55.5%) and intra-graft bone bridging (66.7% vs. 40.7%) was higher in the cortical ring group; however, the difference was not significant. The patient-reported outcomes at 1-year postoperative did not demonstrate significant intergroup differences both in single- and multi-level operations.

Conclusions: Allograft resorption or fracture occurs more frequently with cortico-cancellous than cortical ring allografts. Despite the frequent occurrence of allograft-related complications with cortico-cancellous allografts, the fusion rate was not significantly affected. Due to the higher rate of allograft resorption or fractures and greater subsidence with cortico-cancellous allografts, cortical ring allografts might yield more stable results in ACDF.

Keywords: *Anterior cervical discectomy and fusion, Cortical ring allografts, Cortico-cancellous allografts, Surgical outcomes*

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Anterior cervical discectomy and fusion (ACDF) is commonly used for the treatment of cervical spine degenerative disease and has undergone various modifications and improvements.[1)] The interbody materials can be broadly categorized into autograft, allograft, and various types of cages, including polyether ether ketone (PEEK) and titanium cages. Tricortical iliac autograft was previously considered the gold standard among interbody materials. However, its use has decreased due to drawbacks such as donor site morbidity and prolonged surgical time.[2,3)] Allograft has been recognized for its advantages over titanium cages, including a higher fusion rate, fewer magnetic resonance imaging (MRI) artifacts, and less subsidence. Several reports have suggested that allograft demonstrates better clinical outcomes than autograft.[4-7)] In a study comparing allograft and PEEK cages, no significant difference was observed in terms of fusion rate; however, the incidence of cage subsidence was higher in the PEEK cage group.[8,9)] Currently, allograft such as cortical ring, dense cancellous type, and cortico-cancellous type has been the predominant choice for interbody materials in ACDF.[10-12)] The dense cancellous type of allograft demonstrates faster bone ingrowth than the cortical type.[10,11)] However, it lacks a cortical portion, making it mechanically weak. Consequently, the risk of graft collapse and resorption increases.[11)]

A study comparing cortical ring allograft and autograft in ACDF procedures reported similar radiological and clinical outcomes between the 2 groups.[13)] While cortical allografts are mechanically stronger than cancellous bone and have higher successful outcomes in ACDF procedures, they present caveats such as prolonged time for remodeling and complete incorporation.[14)] Cortico-cancellous allograft comprised a cortical border and a cancellous central portion, amalgamating the strength of cortical bone and the advantages of cancellous bone.[12,14)] Park et al.[12)] reported no significant difference in clinical symptoms and fusion rates between cortico-cancellous and iliac crest autografts at a 2-year follow-up. Recent studies have reported that the rate of morphological changes, including graft resorption or fracture, in cortico-cancellous allografts can reach up to 54%. A group with graft resorption or fracture exhibited an increased incidence of pseudoarthrosis and subsidence. However, these changes did not significantly affect clinical outcomes. Notably, graft morphological changes were more pronounced in cases involving multi-level procedures.[15)]

No study has explored the radiological and clinical outcomes of cortical ring and cortico-cancellous type allografts. Therefore, we aimed to compare the surgical outcomes of cortical ring and cortico-cancellous allografts in ACDF.

METHODS

The study protocol was approved by the Institutional Review Board of Asan Medical Center (IRB No. 2022-0863). Informed consent was waived due to retrospective nature of the study.

Study Design

This study retrospectively analyzed the data of patients who underwent ACDF between July 2016 and August 2019 for cervical myelopathy or radiculopathy and were regularly followed up for over 12 months. Patients who had previously undergone cervical spine surgery or combined posterior fixation and had been diagnosed with tumor, infection, or fracture were excluded. Patients were categorized into 2 groups based on the type of allograft: cortical ring and cortico-cancellous allograft groups. Subsequently, subgroup analysis was performed for both single- and multi-level operations (Fig. 1). All surgeries were performed by 1 orthopedic surgeon (DHL) in a single institution.

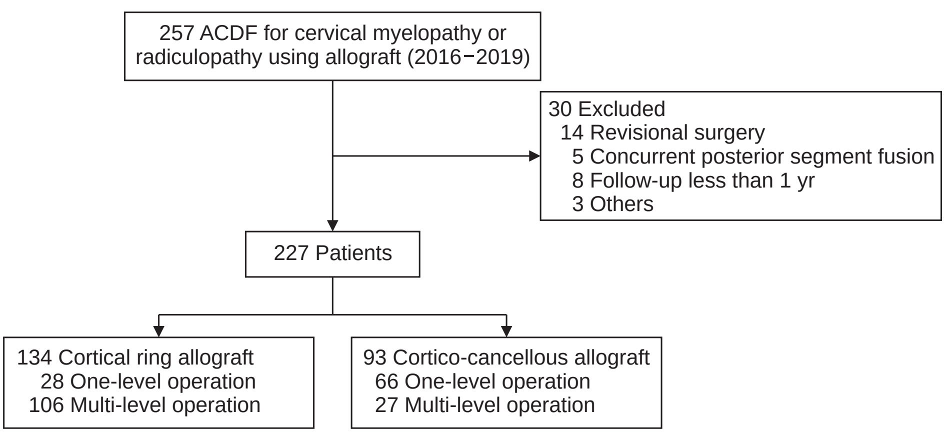

Fig. 1. Patient selection process. ACDF: anterior cervical discectomy and fusion.

Method of Evaluation

For radiological evaluation, we reviewed the pre- and postoperative radiographs of the patients for cervical parameters including C2-7 lordosis, segmental lordosis of interbody fusion, and allograft complications including resorption, subsidence, and fracture. To assess the fusion rate, flexion and extension lateral views were obtained at 6 and 12 months following the surgery. The images were enlarged by 150% to facilitate the evaluation of interspinous motion (ISM) (Fig. 2). The criteria for fusion based on plain radiographic ISM is < 1 mm at the arthrodesis level and > 4 mm at a non-arthrodesed superjacent level (the level above the fused area).[16] Additionally, we examined the multi-axial reconstructed computed tomography (CT) scans obtained at 2 days and 1 year after surgery. Four peripheral margins were evaluated: anterior and posterior margins on sagittal views and left and right margins on coronal views. A bridging bone with cortical density, which was present in at least 1 of these 4 peripheral margins, was categorized as fused.[17] Extra-graft bone bridging (ExGBB) was defined as any bridging bone outside the graft or cage, without a transverse lucent line crossing the peripheral margins of the operated disc space. Meanwhile, intra-graft bone bridging (InGBB) was defined as any cortical or trabecular bridging bone without a transverse, lucent line within the confines of the graft or cage, and that was not outside the graft or cage (Fig. 3).

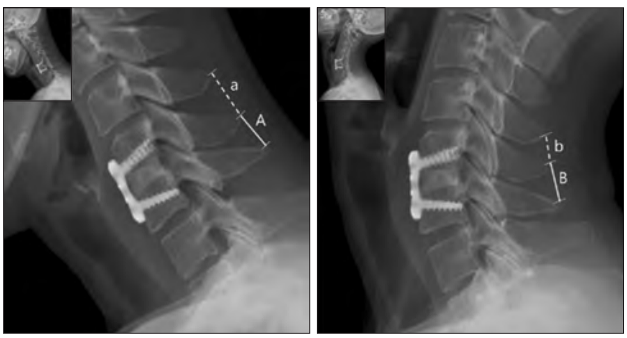

Fig. 2. Interspinous motion (ISM) in cervical lateral radiographic views. The images were enlarged by 150% to facilitate the evaluation of ISM. The ISM was defined as the difference in the interspinous distance between lateral flexion and extension radiographic views on an operative segment (ISM = A – B). The criteria for fusion based on plain radiographic ISM was < 1 mm at the arthrodesis level and > 4 mm at the non-arthrodesed superjacent level (the level above the fused area, a – b).

Significant allograft resorption was defined as a height difference of ≥ 1 mm in the 1-year postoperative CT scan.[15] The amount of graft resorption was calculated by the difference in allograft height measured on CT obtained 2 days and 1 year postoperatively. Significant graft subsidence was defined as a graft migration of > 3 mm into the adjacent vertebral body, as calculated from the immediate postoperative radiographs compared to those obtained at 1-year follow-up.[18] Graft fracture was assessed when the fracture line at the cortical portion of the allograft was detected on the 1-year postoperative CT scan (Fig. 4). Additionally, we assessed the occurrences of allograft complications based on the position of the cage. The position of the cage was considered to be in the middle if the cage center was within ± 5 mm of the center of the vertebral body, anterior if it was positioned more towards the front, and posterior if it was positioned more towards the back. Patient-reported outcome measures, including neck pain visual analog scale (VAS), arm pain VAS, and neck disability index were assessed. These measures were evaluated both before the surgery and at the final follow-up.

Surgical Technique and Allograft Materials

The position of the patient was adjusted to achieve a physiologic or slightly lordotic alignment by placing horizontal

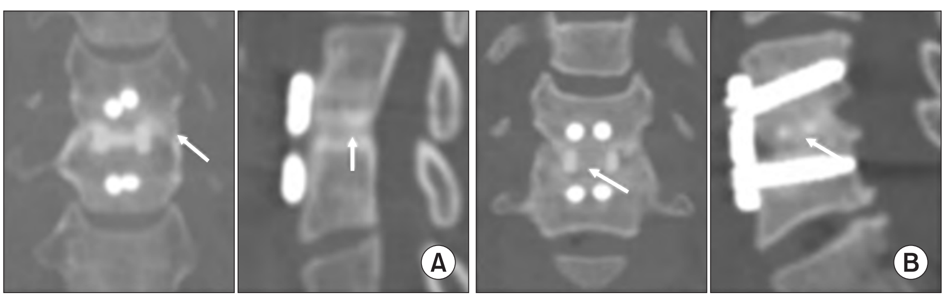

Fig. 3. Extra-graft bone bridging (ExGBB) and intra-graft bone bridging (InGBB) in the multi-axial computed tomography scans obtained postoperatively. (A) ExGBB was defined as any bridging bone outside the graft or cage without a transverse lucent line crossing the peripheral margins of the operated disc space (arrows). (B) InGBB was defined as any cortical or trabecular bridging bone without a transverse, lucent line within the confines of the graft or cage and that was not outside the graft or cage (arrows).

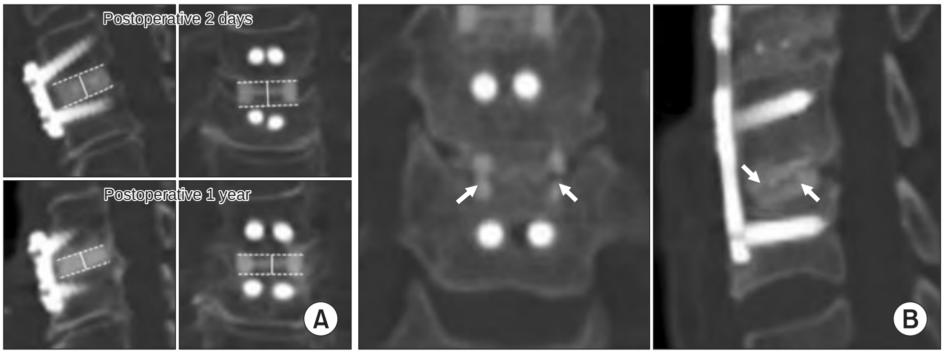

Fig. 4. Allograft resorption and fracture in anterior cervical discectomy and fusion. (A) Allograft resorption was assessed when there was a height difference of ≥ 1 mm in 1-year postoperative computed tomography (CT) scan. (B) Graft fracture was assessed when the fracture line at the cortical portion of the allograft was detected on the 1-year postoperative CT scan (arrows).

padding behind the scapula. After positioning, the intraoperative c-arm was used to confirm the true view of the anteroposterior aspect of the uncovertebral joint. Surgeries were performed through a left-side transverse incision using the Smith-Robinson approach, with the operated segment localized. A box-shaped endplate preparation technique was used to enhance interbody fusion. Anterior compressive pathologies, including bone spurs, discs, and ossification of the posterior longitudinal ligament (PLL), were removed. In cases where radiculopathy symptoms and an MRI indicated the need for root decompression, uncovertebral joint resection was performed. To preserve cervical stability, uncinate process resection was performed minimally to achieve root decompression.[19] Meticulous control of soft-tissue and bone bleeding was implemented to prevent heterotopic ossification. The PLL was resected in cases of preexisting damage due to severe herniation of disc material crossing over the PLL, particularly when the disc fragments were located behind the ligament.

Two types of allograft were utilized: a freeze-dried cortical ring type allograft (SteriGraft Cervical ACF implant, Bone Bank Allografts) and a freeze-dried cortico-cancellous allograft (Cornerstone ASR, Medtronic) (Fig. 5). Allograft size was selected based on intraoperative assessment, and allograft height that tightly fits into the disc space after releasing distraction without significant resistance was selected. An anterior cervical plate was applied for stabilization (Venture, Medtronic). A local autobone graft obtained during osteophyte or endplate preparation was embedded outside of the cage after applying the cervical plate in all cases.[20] To prevent adjacent segment ossification development or adjacent segment disease, we used a short-length plate that slightly overlapped the upper and lower margins of the cranial and caudal level endplates.[21,22] The anterior plate (Venture, Medtronic) allows

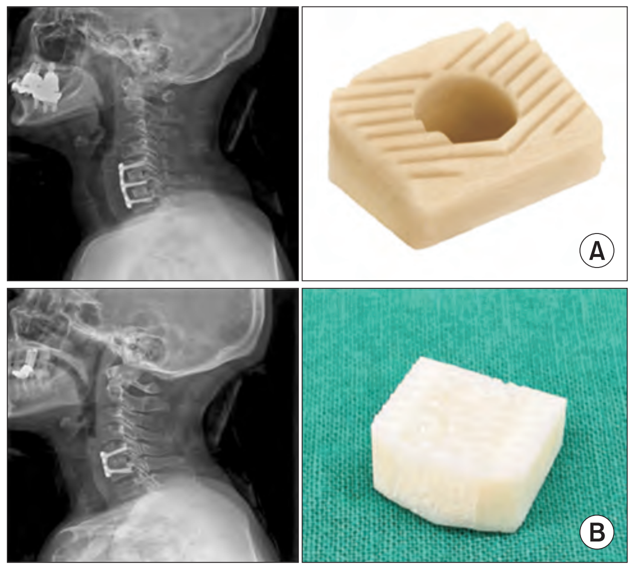

Fig. 5. Allograft materials: cortical ring and cortico-cancellous types. (A) Plain cervical lateral radiograph of a patient operated using cortical ring allograft and the structure of the cortical ring allograft. (B) Plain cervical lateral radiograph of a patient operated using cortico-cancellous allograft and the structure of the cortico-cancellous allograft.

variable-angle screws up to 18° and fixed-angle screws at 10°. We inserted variable screws at the cranial and caudal levels at the largest angle possible.[21,22] We positioned the plate more than 5 mm away from the adjacent disc. Additionally, to increase the fusion rate, we inserted screws that were at least 75% of the vertebral body length.[23]

The same postoperative management was employed for both groups. Following the surgery, a drain was inserted, and the wound was closed in layers. The suction drain was typically removed 1–2 days after the operation. Patients were instructed to wear a postoperative rigid cervical collar (Miami J, Ossur) for 4 weeks after a single-level operation and for 3 months after a multi-level operation.[19,24,25]

Statistical Analysis

All data are presented as mean ± standard deviation or percentile values. Demographic and radiographic results were analyzed by dividing the participants into 2 groups. Continuous variables were compared using Student *t*-test, while categorical variables were analyzed using the chi-square test. Patient-reported outcomes were compared and analyzed between the 2 groups using the Mann-Whitney *U*-test. A *p*-value < 0.05 was considered statistically significant.

RESULTS

Of the 257 individuals, 227 were enrolled in the study. Among them, 134 (59.0%) underwent ACDF with cortical ring allograft, while 93 (41.0%) received cortico-cancellous allograft. No significant differences were observed in demographics between the 2 groups. However, the 2 groups significantly differed in the number of levels operated on, with the cortical ring and cortico-cancellous groups having an average of 2.03 and 1.31 levels, respectively (Table 1).

We conducted a subgroup analysis by dividing the patients into single- and multi-level operation groups. In the single-level operation, no significant differences were observed in patient demographics and complications (Table 2). However, in the multi-level operation, the average number of levels operated was significantly higher in the cortical ring allograft group (2.3 vs. 2.1). No other significant differences were observed in the demographics or complications (Table 3). When comparing the results of single-level operation, the cortico-cancellous allograft exhibited a significantly frequent allograft resorption (24 / 66, 36.4%) compared to the cortical ring allograft (1, 3.7%; $p = 0.001$). Moreover, the cortico-cancellous allograft group demonstrated significantly greater subsidence ($p = 0.038$). However, the fusion rates did not significantly differ between the 2 groups (Table 4). In multi-level operations, cortico-cancellous allografts (5 / 27, 18.5%) resulted in a significantly higher fracture rate than did the cortical ring allograft (5 / 105, 4.7%, $p = 0.030$). Although the fusion rate at postoperative 1 year was higher in the cortical ring group assessed by both ISM (63.2% vs. 55.5%) and InGBB (66.7% vs. 40.7%), the difference was not statistically significant ($p = 0.510$ and $p = 0.500$, respectively) (Table 5).

In the analysis of cage position and allograft complications, the posterior position showed a significantly high rate of subsidence (2 / 10, 20%) and fracture (3 / 10, 30%) in single-level operations, whereas the occurrence of fractures was significantly higher in the middle cage position (8 / 55,

Table 1. Patients Demographics

Variable	Cortical ring allograft (n = 134)	Cortico-cancellous allograft (n = 93)	*p*-value
Age (yr)	56.7 ± 11.2	55.9 ± 12.1	0.595
Sex (male : female)	73 (54.5) : 61 (45.5)	55 (59.1) : 38 (40.9)	0.486
DM	28 (20.9)	12 (12.9)	0.120
HTN	46 (34.3)	32 (34.4)	0.990
Smoking	32 (23.9)	26 (28.0)	0.489
BMI (kg/m^2)	25.0 ± 3.4	24.8 ± 2.9	0.584
Follow-up period (mo)	30.6 ± 14.5	26.6 ± 12.84	0.035*
Number of levels operated	2.03 ± 0.68	1.31 ± 0.51	0.000*
Complication			
Infection	0	0	NA
Reoperation	1 (0.7)	0	0.404
Dural tear	1 (0.7)	1 (1.1)	0.794
Neurologic deterioration	3 (2.2)	0	0.146

Values are presented as mean ± standard deviation or number (%).
DM: diabetes mellitus, HTN: hypertension, BMI: body mass index, NA: not applicable.
*Statistically significant.

Table 2. Patient Characteristics (Single-Level Operation)

Variable	Cortical ring allograft (n = 28)	Cortico-cancellous allograft (n = 66)	*p*-value
Age (yr)	51.1 ± 11.3	55.8 ± 12.9	0.106
Sex (male : female)	16 (59.3) : 11 (40.7)	34 (51.5) : 32 (48.5)	0.647
DM	3 (11.1)	7 (10.6)	1.000
HTN	8 (29.6)	24 (36.4)	0.634
Smoking	8 (29.6)	21 (31.8)	1.000
BMI (kg/m^2)	24.7 ± 3.4	24.6 ± 3.0	0.947
Follow-up period (mo)	32.5 ± 14.1	26.8 ± 13.7	0.077
Number of levels operated	1.00	1.00	1.000
Complication			
Infection	0	0	NA
Reoperation	0	0	NA
Dural tear	0	1 (1.5)	1.000
Neurologic deterioration	0	1 (1.5)	1.000

Values are presented as mean ± standard deviation or number (%).
DM: diabetes mellitus, HTN: hypertension, BMI: body mass index, NA: not applicable.

Table 3. Patient Characteristics (Multi-Level Operation)

Variable	Cortical ring allograft (n = 106)	Cortico-cancellous allograft (n = 27)	*p*-value
Age (yr)	58.2 ± 10.9	56.3 ± 10.3	0.418
Sex (male : female)	57 (53.8) : 49 (26.2)	21 (77.8) : 6 (22.2)	0.029*
DM	24 (22.6)	5 (18.5)	0.796
HTN	37 (34.9)	8 (29.6)	0.656
Smoking	24 (22.6)	5 (18.5)	0.796
BMI (kg/m^2)	25.2 ± 3.5	25.3 ± 2.9	0.893
Follow-up period (mo)	30.1 ± 14.7	26.2 ± 10.8	0.192
Number of levels operated	2.3 ± 0.5	2.1 ± 2.7	0.024*
Complication			
Infection	0	0	NA
Reoperation	0	1 (3.7)	0.772
Dural tear	1 (0.9)	0	1.000
Neurologic deterioration	2 (1.9)	0	1.000

Values are presented as mean ± standard deviation or number (%).
DM: diabetes mellitus, HTN: hypertension, BMI: body mass index, NA: not applicable.
*Statistically significant.

Table 4. Radiographic Results (Single-Level Operation)

Variable	Cortical ring allograft (n = 28)	Cortico-cancellous allograft (n = 66)	*p*-value
Fusion			
6-Month ISM	10 (37.0)	30 (45.5)	0.497
12-Month ISM	21 (77.8)	48 (72.7)	0.795
InGBB	24 (88.9)	49 (74.2)	0.166
ExGBB	17 (63.0)	39 (59.1)	0.818
Allograft complication			
Subsidence			
Amount (mm)	0.81 ± 0.88	1.25 ± 0.91	0.038*
> 3 mm	1 (3.7)	3 (4.5)	1.000
Fracture	0	4 (6.1)	0.319
Resorption	1 (3.7)	24 (36.4)	0.001*

Values are presented as number (%) or mean ± standard deviation.
ISM: interspinous motion, InGBB: intra-graft bone bridging, ExGBB: extra-graft bone bridging.
*Statistically significant.

Table 5. Radiographic Results (Multi-Level Operation)

Variable	Cortical ring allograft (n = 106)	Cortico-cancellous allograft (n = 27)	*p*-value
Fusion			
6-Month ISM	18 (16.7)	5 (18.5)	0.783
12-Month ISM	67 (63.2)	15 (55.5)	0.510
InGBB	71 (66.7)	11 (40.7)	0.500
ExGBB	53 (50.0)	16 (59.3)	0.518
Allograft complication			
Subsidence			
Amount (mm)	1.7 ± 1.3	2.1 ± 1.7	0.162
> 3 mm	14 (13.2)	5 (18.5)	0.539
Fracture	5 (4.7)	5 (18.5)	0.030*
Resorption	52 (49.1)	13 (48.1)	1.000

Values are presented as number (%) or mean ± standard deviation.
ISM: interspinous motion, InGBB: intra-graft bone bridging, ExGBB: extra-graft bone bridging.
*Statistically significant.

14%) in multi-level operations (Table 6). The sagittal alignment between the groups with allograft complications and without complications showed no significant differences in cervical parameters in single-level fusions. However, in multi-level fusions, the allograft complication group showed a significant kyphotic change in the segmental lordosis of fusion levels, decreasing from 7.8° (± 7.0°) 1 month postoperatively to 4.4° (± 7.5°) 1 year postoperatively. In comparison, the no complication group showed a change from 7.3° (± 4.9°) to 7.2° (± 5.5°) over the same period (Fig. 6). The patient-reported outcome measures at 1-year postoperative mark did not reveal a significant intergroup difference between the 2 groups, both in single- and multi-level operations (Table 7).

Table 6. Analysis of Allograft Complications Based on the Location of the Allograft

Variable	Anterior	Middle	Posterior	*p*-value
Single-level (n = 94)	(n = 45)	(n = 39)	(n = 10)	
Subsidence	1 (2)	1 (2)	2 (20)	0.010*
Resorption	12 (26)	11 (28)	2 (20)	0.978
Fracture	0	1 (3)	3 (30)	0.010*
Multi-level (n = 133)	(n = 58)	(n = 55)	(n = 20)	
Subsidence	5 (8)	10 (18)	4 (20)	0.229
Resorption	26 (43)	17 (31)	7 (35)	0.384
Fracture	0	8 (14)	2 (10)	0.010*

Values are presented as number (%).
*Statistically significant using one-way analysis of variance.

DISCUSSION

The selection of an appropriate graft material is crucial for achieving successful bone fusion and optimal clinical outcomes in ACDF.[12] Tricortical iliac crest autograft, known for its superior biological activity, was traditionally considered the gold standard interbody spacer for ACDF.[26] However, its use has decreased due to drawbacks such as donor site morbidity and increased surgical time.[2,3] Recent studies on ACDF have shifted towards alternative graft materials that offer comparable outcomes while bypassing the issues associated with autografts. Additionally, as anterior plating gains popularity, an increasing number of studies advocate the use of allografts in ACDF with plate augmentation, demonstrating improved postoperative clinical and radiological outcomes.[27-29] Allografts are

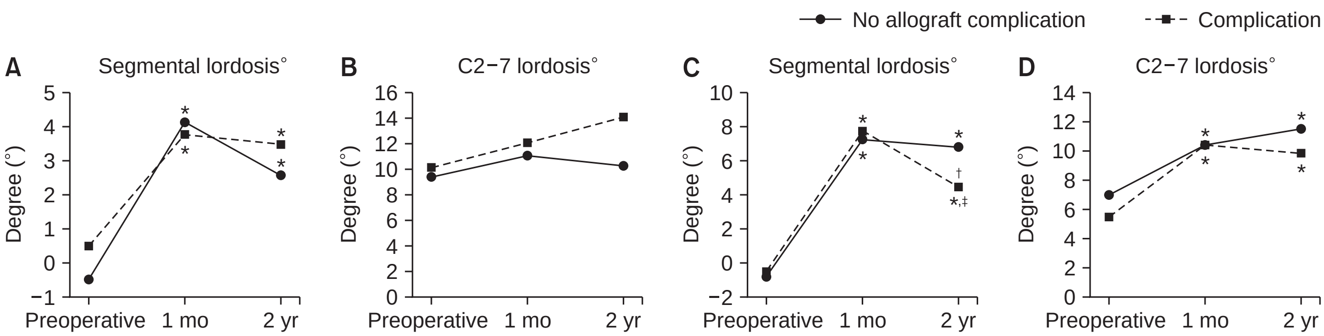

Fig. 6. Changes over time in segmental lordosis and C2-7 lordosis in groups with allograft complications and no complications. (A, B) Single-level operations. (C, D) Multi-level operations. *Significant difference from preoperative assessment. †Significant difference between 2 groups. ‡Significant difference from the prior assessment. $p < 0.05$.

Table 7. Patient-Reported Outcome Measures

Variable		Cortical ring allograft (n = 134)	Cortico-cancellous allograft (n = 93)	*p*-value
Neck pain VAS	Preoperative	4.1 ± 2.7	3.5 ± 2.6	0.200
	Final	2.5 ± 2.4	2.1 ± 2.0	0.270
	p-value	< 0.001*	< 0.001*	
Arm pain VAS	Preoperative	4.5 ± 2.6	4.9 ± 2.9	0.360
	Final	3.4 ± 2.8	2.8 ± 2.6	0.190
	p-value	0.003*	< 0.001*	
NDI	Preoperative	26 ± 17	21.8 ± 19.4	0.200
	Final	11.5 ± 11.3	10.4 ± 10.0	0.520
	p-value	< 0.001*	< 0.001*	

Values are presented as mean ± standard deviation.
VAS: visual analog scale, NDI: neck disability index.
*$p < 0.05$ in the paired *t*-test comparing pre- and postoperative VAS and NDI scores.

recognized as osteoconductive and may offer a certain degree of osteoinductivity, albeit lacking the osteogenic potential of autografts.[30)] Their availability and prevention of donor site morbidity are notable advantages. Moreover, the fusion rates of plated allografts appear comparable to those of autografts.[5)] However, there are some drawbacks to allografts, including cost, variation in osteoinductive potential between different manufacturers based on sterilization techniques and donors, as well as the potential risks of disease transmission and host rejection. Recently, various types of allografts, including cortical ring, cortico-cancellous, and dense cancellous, are utilized as interbody materials in ACDF.[10-12)]

Cortical ring allografts are known to be mechanically stronger than cancellous bone and have demonstrated successful outcomes in ACDF procedures. However, they require prolonged time for remodeling and complete incorporation. Lee et al.[13)] reported that a cortical ring type allograft filled with demineralized bone matrix in a single- or double-level plate-supplemented ACDF surgery demonstrated comparable clinical and radiological outcomes, along with reduced bleeding, when compared to the standard autograft. Other studies have shown that the use of cervical plates significantly reduces graft-related complication rates in 1- and 2-level ACDF with cortical allograft, leading to markedly enhanced arthrodesis.[31)]

A cortico-cancellous allograft is a freeze-dried bone cage that consists of cortical lateral walls and a cancellous center. The cortical portion provides structural support for the disc space, while the cancellous portion acts as a scaffold for bone in-growth, reducing graft subsidence and enhancing fusion rates. Park et al.[12)] suggested that patients treated with cortico-cancellous allograft or autograft for ACDF showed similar clinical and radiologic outcomes, but with a decreased subsidence rate in the cortico-cancellous allograft group. Therefore, cortico-cancellous allograft can be a potential alternative graft material for ACDF.

Dense cancellous allografts exhibit a compressive strength similar to that of cervical endplates, thereby diminishing the likelihood of graft pistoning and settling. They possess a trabeculated and porous structure, which provides a better scaffold for osteoconductive bone ingrowth compared to that of cortical allografts. However, dense cancellous allografts have been associated with high rates of resorption when used in ACDF. Although most segments fused and no patients required revision for symptomatic pseudarthrosis, the resorption of the graft resulted in voids within the graft, with only 53% of levels showing bridging trabeculations covering more than half of the disc space. Despite the theoretical advantages, caution should be exercised when considering the use of dense cancellous allografts in ACDF due to their propensity for resorption.[11)]

In our study, we observed a higher incidence of allograft resorption or fracture in cortico-cancellous allografts than in cortical ring allografts. Several studies highlighted the differences in surgical outcomes between single- and multi-level ACDF.[32-34)] Veeravagu et al.[33)] studied the rates of adverse events and the need for revision surgery in patients undergoing single- versus multi-level ACDF, and they found that cervical reoperations were more common in the multi-level ACDF group. Based on the established differences in surgical outcomes between single- and multi-level operations, we conducted our study by dividing groups into single- and multi-level for evaluation. Cortico-cancellous allografts resulted in significantly greater subsidence and resorption than cortical ring allografts in a single-level operation. These findings are likely attributed to the mechanical properties of the cortico-cancellous type, which may undergo dissociation or deformation under compressive forces, making them mechanically weaker than cortical ring type allografts. According to Kwon et al.'s study on the biomechanical analysis of allograft spacer failure,[35)] when comparing 3 types of allografts used in ACDF (cortical only, cortical cancellous, and cortical lateral walls with a cancellous center), the cortical lateral walls with a cancellous center exhibited the highest stress on the cortical bone of the spacers and the endplate around the posterior margin of the spacers. They concluded that cervical spacers with a smaller cortical component could be a risk factor for allograft spacer failure and subsidence, especially during flexion and extension.

On the other hand, no statistically significant differences were observed in subsidence and resorption between the 2 types of allografts in multi-level operations (1.7 mm vs. 2.1 mm, 49.1% vs. 48%). Interestingly, fracture complications of the allograft were significantly higher in the cortico-cancellous type group in multi-level operations (4.7% vs. 18.5%). The incidence of resorption was higher in multi-level than in single-level operations. This increase may be attributed to the higher number of allografts used in multi-level operations. It is likely that in multi-level operations, the manifestation of allograft complications occurred in the form of fractures. The difference in the pattern of allograft complications between a single- and multi-level operations may be due to the varying biomechanical characteristics depending on the number of surgical levels involved. Yang et al.[15)] suggested a high rate of graft morphologic changes (54.3%) in cortico-cancellous allografts. These morphologic changes, such as graft resorption or fracture, were associated with increased pseudarthrosis, subsidence, and decreased postoperative segmental lordosis. Notably, these morphologic changes did not significantly impact the clinical outcomes. The higher rate of morphologic changes observed in cortico-cancellous allografts may be attributed to their mechanical properties.

In multi-level operations, allograft complications, including resorption, subsidence, and fracture, resulted in kyphotic changes in segmental lordosis. According to Yamagata et al.,[36)] the operated segment lordosis significantly decreased in the group with cage subsidence compared to the no subsidence group. Additionally, Yang et al.[15)] reported a significant difference of –3.1° in segmental lordosis between the postoperative and final state in the group with allograft morphologic changes and a difference of –1° in the group with unchanged segments, indicating more kyphotic changes in the group with morphologic changes. This could be due to the decrease in segment height caused by cage complications.

In this study, in the multi-level group, the subsidence rates were 13.2% (14 / 106) for cortical ring allograft and 18.5% (5 / 27) for cortical cancellous allograft. Subsidence is the most commonly reported cage-related complication, with an incidence of 21% (according to a systematic review by Noordhoek et al.).[37)] That review included various types of cages, such as PEEK, titanium, cage-screw-combination, and polymethyl-methacrylate (PMMA), and showed that the use of PEEK or titanium cages or cages with integrated screws can lower the risk of subsidence. However, the type of allograft that we used in our study was not investigated in the review by Noordhoek et al.[37)] A study by Yson et al.[38)] compared subsidence rates between allograft and PEEK cages and reported no statistically significant difference between the PEEK group (29%, 25 / 85) and the allograft group (28%, 9 / 32). That study concluded that the choice between PEEK and allograft as spacers in ACDF did not significantly affect the subsidence rate or clinical outcomes. In the current study, we observed a lower subsidence rate compared to previous studies. We implemented the use of the Miami J brace, a rigid type of neck brace, for 12 weeks. According to Guo et al.,[19)] excessive resection of the uncovertebral joint can compromise cervical spine stability, particularly during lateral flexion and rotation. The uncovertebral joints play a crucial role in limiting these movements. Therefore, to mitigate the cage stress concentration after ACDF, the use of a rigid neck brace that restricts lateral flexion and rotation is recommended.

To evaluate fusion in ACDF, we used 3 widely used methods. One method used 150% magnified ISM, and the other 2 methods used CT-based ExGBB and InGBB. Among these, ExGBB has been proven to have the highest diagnostic sensitivity and specificity for detecting pseudarthrosis compared to all the other radiographic criteria.[39] According to Song et al.,[16] the method of measuring 150% magnified ISM demonstrated accuracy that was comparable to CT. Park et al.[20] reported a difference between 6-month ISM and 1-year ISM, with a fusion rate of 40% at 6 months, 80% at 12 months, and 88% at 24 months, indicating a significant difference between the early 6-month and 12-month periods. These findings are consistent with those seen in our study.

The fusion rate of ACDF is known to be high; however, recent reports have suggested that pseudarthrosis is a common complication after ACDF, particularly for multi-level operations. In our study, the fusion rate was 88% for single-level cases and 66% for multi-level cases. Other studies have shown the fusion rate for single-level cases to be higher than that for multi-level cases, as multi-level cases are diagnosed as pseudarthrosis, if even a single segment does not meet the fusion criteria.[16,20,39] In the study by Park et al.,[20] the fusion rate at 12 months in the group using allografts with an average fusion level of 1.5 was reported to be 80% when assessed using the ISM method, 88% by the InGBB method, and 74% by the ExGBB method. Wewel et al.[40] reported that the incidence of pseudarthrosis was higher in patients with 4-level ACDF (56%, 9 / 16) compared to those with 3-level ACDF (42%, 24 / 56). However, pseudarthrosis did not affect clinical outcomes.[15,20]

In single-level fusions, subsidence and fractures occurred significantly when the allograft was inserted in the posterior position. In multi-level fusions, allograft fractures occurred significantly when the allograft was positioned in the middle or posterior locations. The study by Yamagata et al.[36] on cage subsidence and cervical alignment showed that on the fusion level, the cage size and cage position were significantly related to cage subsidence. Cage positions were analyzed by categorizing them into grade 0 when the cage was within 2 mm of the anterior margin of the plate and grade 1 when the cage was more than 2 mm away. A grade 1 cage position resulted in a significantly higher risk of cage subsidence compared to a grade 0 position and they concluded that excessive distraction at the fusion level should be avoided and the cage position should be adjusted to the anterior vertical line. Additionally, a study on posterior lumbar interbody fusion reported that posterior cage positioning on the vertebral endplate was associated with a higher risk of subsidence.[41] These findings are similar to those of our study, where cage subsidence or fractures occurred significantly when positioned more towards the back.

Our retrospective study has several limitations. First, the allograft was randomly selected without consistent criteria, resulting in an uneven distribution of cortical ring and cortico-cancellous allografts between the single- and multi-level operations. This could have introduced a potential bias when comparing the 2 groups. Second, the number of surgical levels differed between the cortical ring and cortico-cancellous allograft groups in the multi-level operations. Although the difference in levels (2.3 vs. 2.1) was not substantial, it could be a limitation of this study as it may have impacted the results. Third, the lack of reliability assessment for radiographic assessment is another limitation of this study. Finally, there is inconsistency in allograft complications such as subsidence, resorption, and fracture between the single- and multi-level operations. This might be attributed to differences in mechanical characteristics between the single- and multi-level operations; however, further evaluation through biomechanical studies is necessary to better understand these differences.

The present study demonstrated that allograft resorption or fracture occurs more frequently with cortico-cancellous than with cortical ring allograft. Cortico-cancellous allografts resulted in significantly greater subsidence in a single-level operation. Furthermore, although not statistically significant, a large difference was observed in the fusion rate in a multi-level operation (66.7% vs. 40.7%), with the cortical ring allograft showing a higher fusion rate, warranting further verification. Due to the higher rate of allograft resorption or fracture, and significantly greater subsidence with cortico-cancellous allograft, cortical ring allografts may yield more stable results for ACDF.

CONFLICT OF INTEREST

Dong-Ho Lee is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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