Analysis of the Fusion and Graft Resorption Rates, as Measured by Computed Tomography, 1 Year After Posterior Cervical Fusion Using a Cervical Pedicle Screw

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■ BACKGROUND: **We previously showed that cervical pedicle screw (CPS) placement is safe even with the freehand technique. The posterolateral fusion rate 1 year after CPS placement, as measured by computed tomography (CT), is reported here. The graft resorption rates when different graft materials were used were also analyzed.**

■ METHODS: **Between 2012 and 2015, 93 patients underwent posterior cervical fusion surgery with the CPS from C2 to C7. Of these patients, 56 consented to CT scans immediately and 1 year after surgery. These patients formed the present study group. The patients were categorized according to whether the graft material was local bone, allograft, or a mixture. Graft volume was measured at both CT scans. Graft resorption rate was determined by comparing the 2 scans. Radiologic fusion was assessed on the 1 year postoperative CT scan and radiography.**

■ RESULTS: **The reason for surgery was trauma ($n = 19$), degenerative disease ($n = 35$), tumor ($n = 1$), and spondylitis ($n = 1$). Surgery was performed with CPS fixation and decompression. Even although iliac bone grafting was not performed, the overall fusion rate was 98.2% (55/56). The single fusion failure case received a mixture of local bone and allograft. Although the allograft group showed the greatest graft resorption rate (91.5%), all patients in this group had a bony bridge that crossed the facet joint on the 1 year CT scan.**

■ CONCLUSIONS: **CPS placement yielded a posterolateral cervical fusion rate of 98.2%. Despite the high resorption rate of allograft only, this material yielded fusion rates that were similar to those of the other materials. Thus, the strong fixation power of CPS might compensate for the delayed fusion and high resorption rates of allograft bone chips.**

INTRODUCTION

The fusion materials and instrumental techniques used to achieve spinal fusion have developed rapidly and have decreased the morbidity associated with iliac crest harvest, which includes infection or chronic donor-site pain.[1-7] However, nonunion after spine surgery has been one of the major complications until now.[8,9]

We previously showed that cervical pedicle screw (CPS) placement is safe even when the freehand technique is used.[10,11] However, we have not yet reported the rate of fusion in the follow-up period. The present report details the rate of posterolateral fusion 1 year after CPS placement, as assessed by computed tomography (CT) and dynamic radiography. Whether iliac bone harvest is necessary for posterior cervical spine surgery if a pedicle screw is used rather than a lateral mass screw is discussed. In addition, the effect of using different bone graft materials on the amount of bone graft material resorption was assessed. Whether a high resorption rate impaired the fusion rate was determined.

METHODS

Between March 2012 and June 2015, 93 patients underwent posterior cervical fusion surgery with a CPS from C2 to C7. All patients then underwent immediate postoperative 1-mm thin-slice CT. Of

Key words
- Allograft
- Autograft
- Cervical pedicle screw
- Fusion
- Local bone
- Iliac bone
- Resorption

Abbreviations and Acronyms
CPS: Cervical pedicle screw
CT: Computed tomography

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the 93 patients, 56 also underwent 1-mm thin-slice CT scanning and dynamic cervical radiography minimally 1 year after surgery. These 56 patients formed the cohort of the present study. Of the remaining 37 patients, 32 refused the postoperative 1-year CT scan, and 5 died before the scan could be performed. This study was approved by the institutional review board.

Preoperative Characteristics of the Follow-Up Study Cohort

The initial diagnoses of the 56 patients in the follow-up cohort were trauma ($n = 19$), tumor ($n = 1$), spondylitis ($n = 1$), and degenerative disease, including cervical spondylotic myelopathy ($n = 12$), ossification of the longitudinal ligament ($n = 10$), and foraminal stenosis ($n = 13$). The trauma consisted of fracture, dislocation, or cervical cord injury associated with compressive lesion. The primary instrument choice was a pedicle screw that was placed by using the freehand technique if the outer diameter of the cervical pedicle exceeded 3.0 mm on an axial CT scan.

Table 1 shows the preoperative characteristics of the 56 patients. Seven were female and 49 were male. The patients were on average 59.8 years old (range, 29–83 years), and the mean follow-up duration was 20.2 months (range, 12–32 months). The mean fusion level from C2 to C7 was 2.3 (range, 1–5). In patients who lacked a condition that could affect normal bone homeostasis, the bone mineral density was measured if the patient was >50 years old if female or >60 years old if male. Of the 56 patients, 26 underwent bone mineral density analysis. Three patients had a T score of less than −2.5 and were considered to have osteoporosis. Of the 56 patients, 27 smoked and 13 had diabetes mellitus. One patient used steroids for an extended period to treat chronic obstructive pulmonary disease. There were 2 patients with leukemia, 1 with depression, 1 with amyotrophic lateral sclerosis, 1 with chronic obstructive pulmonary disease, 3 with cardiovascular disease, and 1 with tumor.

Table 1. Preoperative Characteristics of the Follow-Up Cohort

Characteristics	Total Number of Patients ($n = 56$)
Age (years), mean (range)	59.8 (29.0–83.0)
Sex, male:female	49:7
Osteoporosis (number of patients)*	3
Smoker, yes:no	27:29
Diabetes mellitus, yes:no	13:43
Steroid user, yes:no	1:55
Medical illness (number of patients)	
Leukemia	2
Tumor	1
Depression	1
Amyotrophic lateral sclerosis	1
Chronic obstructive pulmonary disease	1
Cardiovascular disease	2
Arrhythmia	1
Reason for surgery (number of patients)	
Trauma†	19
Foraminal stenosis	13
Cervical spondylotic myelopathy	12
Ossification of longitudinal ligament	10
Infection	1
Tumor	1

*Osteoporosis (T score <-2.5).
†The trauma led to fracture or dislocation or cervical cord injury associated with compressive lesion.

Surgical Techniques and Patient Classification According to the Different Fusion Materials

The entry point of the screw was determined from the sagittal and axial CT scan images: the entry point was defined as the notch level in the sagittal plane and medial to the lateral border of the superior articular process by one quarter of its width in the axial plane. The entry points were slightly modified depending on the CT anatomy of each patient. Our pedicle screw insertion technique is described in more detail in a previous article.[11] As described previously, the most important factors for the safe and accurate placement of CPSs are as follows: the planning of the screw entry point on the basis of information from the preoperative CT scan, the achievement of an adequate medial angle for screw insertion through the use of a curved small pedicle probe, the ability to detect pedicle breach with a ball-tip probe, the proper conversion to a lateral mass screw when a breach is detected, and the ability to properly interpret the intraoperative anteroposterior radiographic images after screw insertion. All these technical steps were performed in all patients to ensure that the CPSs were safely placed.[11]

During surgery, autologous local bone could be obtained for posterolateral fusion if central decompression was performed via laminectomy. Decompression was performed by using subtotal laminectomy (i.e., half the amount of laminae) at the most cranial and caudal levels, and total laminectomy at the middle level. To use lateral mass as a fusion bed, the junction between the lamina and lateral mass was cut with a 1.5-mm match head–type burr. Cancellous bone was exposed by drilling with a 3.0-mm match head–type burr on the posterior surface of the lateral mass and inside the facet joint. Autologous local bone chip and/or allograft bone chips (TBI Inc., San Rafael, California, USA; 30 mL) were used for posterolateral fusion (i.e., an onlay bone graft on the decorticated lateral mass and inside the facet joint). Thirty-one patients received both autologous local bone chips and allograft bone chips (30 mL) for posterolateral fusion. Six patients did not consent before surgery to the use of additional allograft bone because of the cost. For these patients, only local bone was used for posterolateral fusion. The pathology of the remaining 19 patients did not necessitate central decompression or laminectomy (fracture, dislocation, or foraminal stenosis), and thus only allograft bone chips (30 mL) were used for posterolateral fusion. Iliac bone harvest was not performed in any of the 56 patients.

The patients were classified into 3 groups on the basis of whether local bone ($n = 6$), allograft ($n = 19$), or a mixture ($n = 31$)

Table 2. Preoperative Characteristics of the Groups Whose Fusion Material Was Local Bone, Allograft, or Both

Characteristics	Local Bone Only (n = 6)	Allograft Only (n = 19)	Local Bone and Allograft (n = 31)	*P* Value
Age (years)	58.2 ± 15.3	55.9 ± 10.5	59.8 ± 11.1	0.155
Sex, male:female	4:2	17:2	28:3	0.263
Smoker	2	9	19	0.711
Diabetes mellitus	3	3	7	0.222
Medical illness	1	1	7	0.270
Osteoporosis	0	2	1	0.081
Reason for surgery				<0.001
Trauma	1	6	12	
Cervical spondylotic myelopathy	2	0	10	
Ossification of longitudinal ligament	2	0	8	
Foraminal stenosis	0	13	0	
Infection	0	0	1	
Time for second follow-up	17.0 ± 4.2	16.9 ± 5.4	14.4 ± 4.5	
Time for radiography follow-up	18.0 ± 4.6	23.3 ± 7.5	18.7 ± 6.8	

Values are n or mean ± standard deviation.

was used for posterolateral fusion. Table 2 shows the basic characteristics and fusion rates of each group. The 3 groups did not differ in terms of age, sex, smoking status, presence of diabetes mellitus, or osteoporosis, but all 13 of the patients with foraminal stenosis were in the allograft-only group and constituted 68.4% of this group of 19 patients ($P < 0.001$ compared with the other 2 groups). As shown in Table 3, the mean fusion level was different in the 3 groups ($P = 0.003$).

Postoperative Follow-Up and Image Assessment

All patients underwent postoperative CT within 5 days of surgery to identify the location of the pedicle screw.

The patients were followed up by outpatient clinic visits 1, 3, 6, 12, and 24 months after surgery. At each visit, the numeric rating scale was used to measure neck pain, and cervical radiography, including flexion and extension images, was obtained. Cervical CT was also performed 12 months after surgery if the patient consented.

Table 3. Fusion Levels in the Local Bone, Allograft, and Mixture Groups

Characteristics	Local Bone Only (n = 6)	Allograft Only (n = 19)	Local Bone and Allograft (n = 31)	*P* Value
Fusion levels				
1	1	10	7	
2	3	8	6	
3	1	1	10	
4	1	0	6	
5	0	0	2	
Mean fusion level	2.33 ± 1.03	1.53 ± 0.61	2.25 ± 1.15	0.003

Values are n or mean ± standard deviation.

Radiologic fusion was deemed to have occurred when there was both stability on a dynamic view (i.e., the motion between the adjacent spinous processes between the fusion segment was <2 mm) and the CT sagittal image showed that a contiguous bony bridge had formed.

The volumes of the graft immediately and 1 year after surgery were determined by summing the axial CT scan area by using our picture archiving and communication system (PetaVision 2.1, Gangneung, Korea). The bone resorption amount was determined by comparing the graft volumes immediately and 1 year after surgery. The bone resorption rates when the 3 graft materials (local bone, allograft, and a mixture of local bone and allograft) were used were calculated (Figure 1).

The patient groups were compared by using the χ^2 test, 1-way analysis of variance test, or the Kruskal-Wallis test. P values less than 0.01 were considered to indicate statistical significance.

RESULTS

After surgery, none of the patients showed symptoms that were associated with vertebral artery injury or stenosis.

One-year postoperative cervical CT was performed on average 15.5 months (range, 12—29 months) after surgery. Analysis of the CT scan and radiographic data showed that only 1 patient in the mixture group showed fusion failure during the follow-up period (Figure 2). Thus, the overall fusion rate was 98.2% (55/56) in our series, even although iliac bone grafting was not performed. Table 4 shows the mean neck pain scores (as measured by using the numeric rating scale) of the local bone, allograft, and mixture groups 1 month after surgery and at the last follow-up

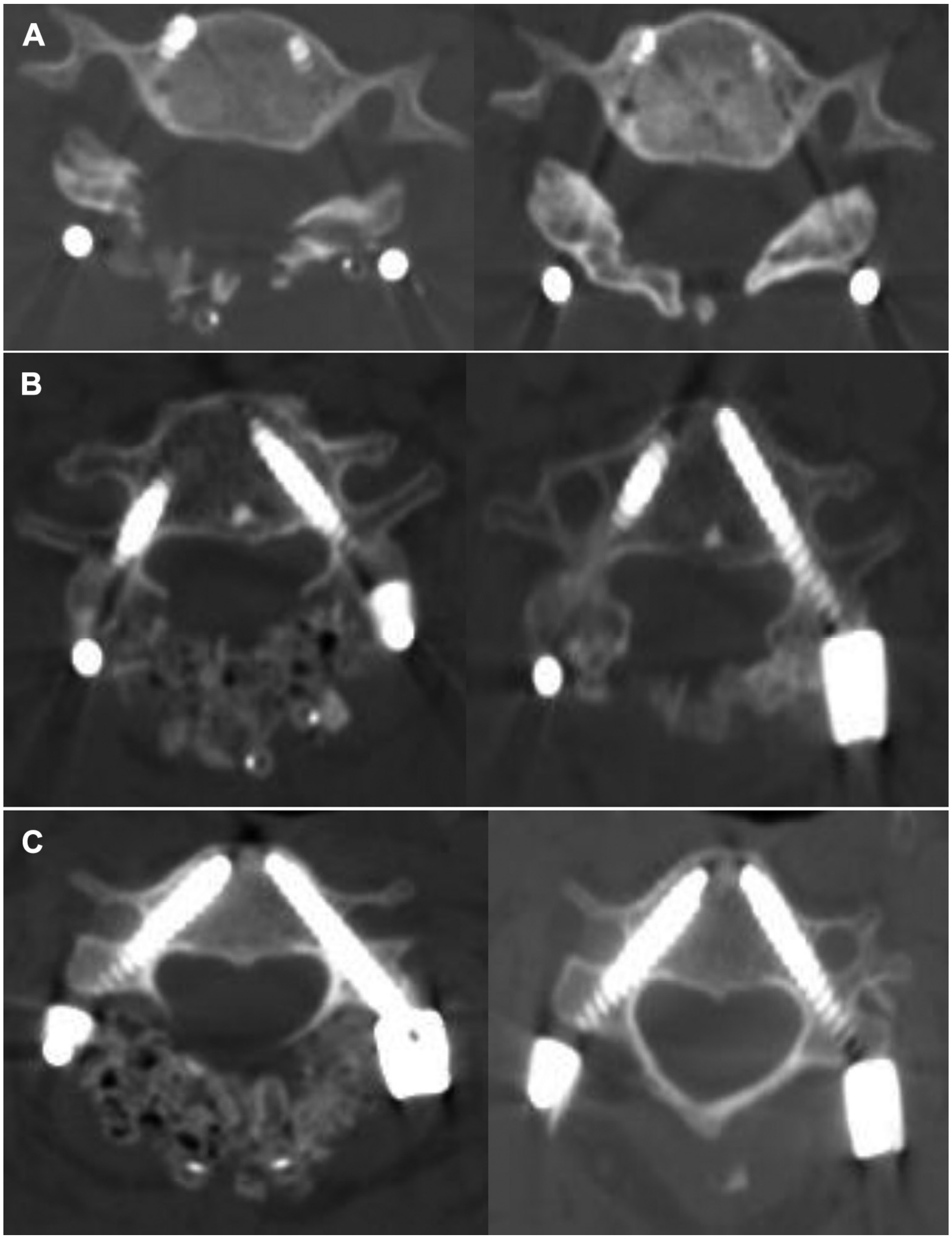

Figure 1. Axial computed tomography (CT) scan images show the changes in graft resorption according to the type of graft material. The timing of the left-side CT scan indicates immediately after surgery and that of the right-side CT scan indicates at least 1 year after surgery in the local bone (**A**), mixture (**B**), and allograft (**C**) groups.

visit. In the local bone group, the scores decreased from 1.8 ± 1.60 to 0.5 ± 1.23. The allograft group scores decreased from 2.0 ± 2.00 to 0.8 ± 1.32. The mixture group scores decreased from 1.7 ± 1.61 to 1.42 ± 1.65. The 3 groups did not differ significantly in terms of neck pain at either 1 month after surgery or at the last follow-up visit.

The graft volumes of the 3 groups immediately after surgery and at last follow-up were then compared to assess the effect of posterolateral fusion material on graft resorption (Table 5). For the local bone group, the mean graft volume decreased from 5.7 ± 3.03 to 2.3 ± 0.82. For the allograft group, the volume decreased from 17.3 ± 4.07 to 1.7 ± 2.75. For the mixture

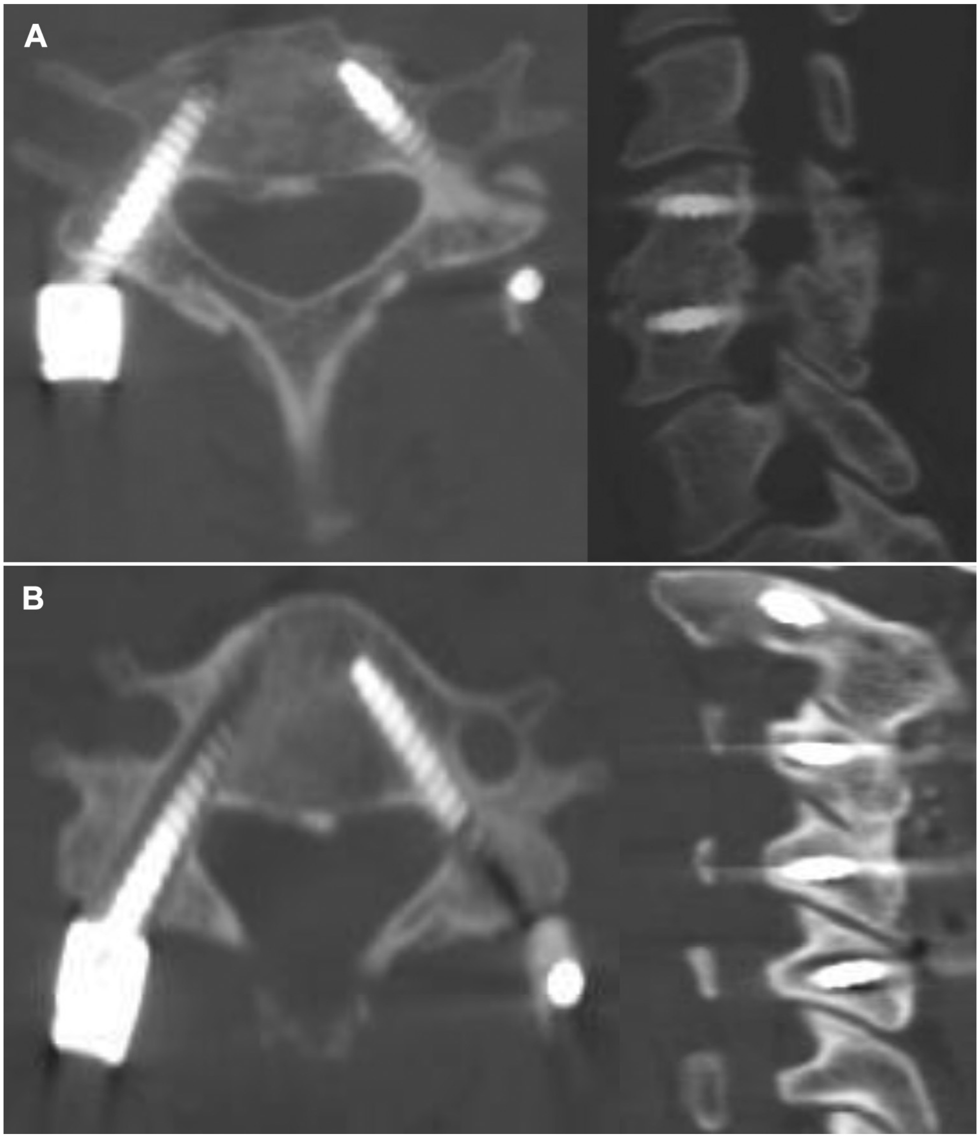

Figure 2. Although marked resorption is evident on the axial computed tomography (CT) scan, facet joint fusion is visible on the sagittal CT scan in the allograft patient group (**A**). The axial and sagittal CT scans of the mixed patient group show a halo around the screw, indicating nonunion (**B**).

group, the volume decreased from 22.1 ± 5.73 to 5.7 ± 3.81. The mean resorption rates (standard deviation) of the 3 groups were 56.2% (15.35), 91.5% (14.14), and 75.9% (14.82), respectively. These differences were statistically significant, as determined by analysis of variance ($P < 0.001$).

DISCUSSION

Lateral mass screw fixation has been the standard method of posterior cervical spine fixation and stabilization until now. A recent review of this method[12] cited the numerous studies that reported the posterolateral fusion rates achieved.[12-23] The mean reported fusion rate associated with lateral mass screw fixation was 97.0% (range, 91–100%). In 3, 1, 2, and 2 studies, the graft material used for fusion was iliac bone,[13,14,19] local bone,[18] local bone with allograft,[15,20] and local bone with demineralized bone matrix,[16,22] respectively. In another 3 studies, the graft materials used for fusion were not described.[17,21,23] The present study on CPS fixation reported a fusion rate after 1 year of 98.2% (55/56). This fusion rate is similar to those associated with lateral mass screw fixation. However, nearly half of the patients in 1 study on lateral mass screw fixation also underwent simultaneous anterior surgery.[22] Moreover, although fusion assessment is most accurate when CT scanning is combined with dynamic

Table 4. Mean Neck Pain During Follow-Up, as Measured by Using the Numeric Rating Scale, and Fusion Failure in the Local Bone, Allograft, and Mixed Groups

Mean Numeric Rating Scale Score Change of Neck Pain	Local Bone Only (n = 6)	Allograft Only (n = 19)	Local Bone and Allograft (n = 31)	*P* Value
Time after surgery (months)				
1	1.83 ± 1.60	2.00 ± 2.00	1.76 ± 1.61	0.975
3	0.67 ± 1.83	1.94 ± 1.75	1.52 ± 1.33	0.194
6	0.50 ± 1.22	1.38 ± 1.59	1.57 ± 1.60	0.273
12	0.50 ± 1.23	0.94 ± 1.30	1.36 ± 1.85	0.520
Last follow-up visit	0.50 ± 1.23	0.88 ± 1.32	1.42 ± 1.65	0.302
Number with fusion failure at the last follow-up	0	0	1	0.663

Values are mean ± standard deviation except where indicated otherwise.

radiography,[24] only 4 studies used CT for fusion assessment.[12] By contrast, we used both CT scanning and dynamic radiography. In addition, several studies did not include screw loosening or pullout in their definition of fusion failure.[13,15,19] These possibilities were included in our definition of fusion failure: no cases of these events were detected in the 1-year follow-up CT scans. Furthermore, none of the studies used allograft bone chips only as the fusion graft material in posterior cervical fusion surgery. By contrast, 34% of the patients (19/56) in the present study received allograft bone only. Despite the high resorption rate of this material, all 19 of these patients showed fusion (Figure 2A).

The biological process of bone formation requires 3 critical elements: osteoinductive factors that promote the osteoblastic differentiation of pluripotential stem cells, osteogenic cells that have the capacity to synthesize new bone, and the presence of an osteoconductive scaffold that facilitates neovascularization and supports the ingrowth of bone. Unlike other graft substitutes, autogenous bone possesses all 3 of these essential bone-formation properties. As a result, autologous bone grafts are the most common source of graft material for spinal fusion.[25-27] However, obtaining bone from the iliac crest has several disadvantages, namely, it increases operative time, blood loss, and donor-site morbidity. Up to 30% of all patients undergoing iliac crest bone graft harvesting experience complications postoperatively, including infection, hematoma, nerve or vascular injury, fracture, persistent pain, abdominal herniation, and pelvic instability. The amount of autograft available for transplantation may also be insufficient in children as well as in adults who require revision surgery or fusion of multiple spinal segments.[25,27-30] Although allograft can be used in such cases as an alternative, it lacks osteoinductive potential and osteogenic cells.[31] This factor explains why onlay grafts with allograft bone chips yield inferior fusion rates compared with when autograft bone chips are used, especially in posterior thoracic or lumbar fusion.[27,32-35] Nevertheless, it is accepted that interpositional use of tricortical allograft bone is suitable for single-level anterior cervical, lumbar fusion, or posterior C1-2 fusion; it is also accepted that allograft bone chips can be used in scoliosis surgery in adolescents.[27,36-40] Only 1 study of posterior cervical fusion with allograft bone chips alone has been reported previously. This report described the outcomes of 3 morbidly obese patients who underwent posterior cervical fusion with allograft bone chips to avoid the donor-site morbidity associated with iliac crest autograft harvesting. Fusion failed in all 3 cases, and the investigators recommended that iliac bone should be used in morbidly obese cases.[41] Thus, the literature to date suggests that allograft bone chips alone are not suitable for posterior cervical spinal surgery.

Table 5. Change in Mean Graft Volume and Resorption Rate in the Local Bone, Allograft, and Mixture Groups

	Local Bone Only (n = 6)	Allograft Only (n = 19)	Local Bone and Allograft (n = 31)	Total (n = 56)	*P* Value
Mean graft volume (mL) immediately after surgery or at the last follow-up visit (mean ± standard deviation)					
Immediately after surgery	5.7 ± 3.03	17.3 ± 4.07	22.1 ± 5.73	17.3 ± 7.42	
At the last follow-up visit	2.3 ± 0.82	1.7 ± 2.75	5.7 ± 3.81	3.9 ± 3.42	
Mean graft resorption rate* (%) at last follow-up, mean ± standard deviation	56.2 ± 15.35	91.5 ± 14.14	75.9 ± 14.82	73.7 ± 19.38	<0.001

*Resorption rate was calculated as (1−graft volume at last follow-up/graft volume immediately after surgery) × 100%.

The reason allograft bone has been associated with fusion failure in the past reflects the fact that grafted bone chips become incorporated into the developing fusion mass as a result of several biological events, namely, hemorrhage, inflammation, vascular invasion, and the replacement of graft material with new bone. When allograft bone is used, this remodeling process occurs more slowly and there is greater resorption of the graft compared with autograft bone. The incorporation of allograft may also be delayed because of a host immunologic response. Genetic incompatibility between the donor and recipient is associated with increased allograft resorption.[27,39,42,43] Our present study also showed that allografts had the highest resorption rate. We speculate that the CPS may compensate for the delayed fusion and high resorption rate of allograft bone chips better than the lateral mass screw because its fixation power is stronger; as a result, the CPS may maintain the construct for a longer period, thus allowing remodeling to be completed.

Cervical spinal facet joints are in the oblique direction and are tightly stacked to create nearly a solid column of interarticular bone or lateral mass. This type of facet joint is used as a template in patients undergoing posterior cervical fusion because this is the only facet joint that can provide a vertical compression force on the bone graft among posterolateral structures. In addition, the translational or rotational moments generated in the cervical spine are a fraction of those seen in the lumbar spine. Bone formation in the cervical facet joint is mechanically optimized in this environment.[44] All the posterolateral fusions in our series were inside the facet joints despite the considerable graft resorption in the allograft group. We believe that these environmental advantages facilitated the high fusion rates that were seen even when only allografts were used for posterolateral cervical fusion.

Despite the partial bony fusion on the laminectomy site in the local and mixed bone groups (**Figure 1A,B**), we believe that another important factor for bone fusion is the size of the bony fusion bed, which should be as large as possible. For this reason, we consider laminoplasty a valid alternative decompression method. However, we found a high resorption rate (91.5%) in the allograft group even with a large fusion bed (**Figure 1C**) (i.e., allograft group with no laminectomy), but this resulted in all facet joint fusions. Although laminoplasty provided a wide fusion bed, it did not provide autograft bone without harvesting the iliac bone. However, laminoplasty could have other advantages that are not provided by laminectomy, such as a small dead space and protection of neural structure. These considerations and the results presented in this study suggest that CPS placement combined with laminoplasty and posterolateral fusion using only allograft bone chips could be an ideal option for posterior cervical spinal surgery.

Our follow-up cohort had several factors that are known to impair spinal fusion, namely, an older age, smoking, diabetes, steroid use, osteoporosis, and fusion level.[6,9,24,44,45] However, the autograft, allograft, and mixture subgroups in the cohort did not differ significantly in terms of these variables except fusion level.

CONCLUSIONS

In our series, the overall posterior cervical fusion rate using the CPS was 98.2% (55/56) even although iliac bone grafting was not performed. The single fusion failure involved the use of a mixture of local bone and allograft. CPS fixation with allograft chips was associated with marked graft resorption (91.5%); nevertheless, all patients in this group showed complete facet fusion.

We believe that the CPS could compensate for the delayed fusion and high resorption rate of allograft bone chips because its strong fixation power has the potential to maintain the construct in place for a longer period, thus allowing bone remodeling to be completed.

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