Neurospine 2024;21(2):525-535.
https://doi.org/10.14245/ns.2347132.566

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

Corresponding Author
Sang Ryong Jeon
https://orcid.org/0000-0002-8340-7978

Department of Neurological Surgery, Asan Medical Center, University of Ulsan College of Medicine, 88 Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea
Email: srjeon190@gmail.com

Received: October 31, 2023
Revised: January 20, 2024
Accepted: January 25, 2024

Are There Advantages in Cervical Intrafacetal Fusion With Minimal Posterolateral Fusion (PLF) Compared to Conventional PLF in Posterior Cervical Fusion?

Sun Woo Jang[1], Sang Hyub Lee[2], Jeong Kyun Joo[3], Hong Kyung Shin[1], Jin Hoon Park[1], Sung Woo Roh[1], Sang Ryong Jeon[1]

[1]Department of Neurological Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
[2]Department of Neurosurgery, Spine Center, The Leon Wiltse Memorial Hospital, Suwon, Korea
[3]St. Mary Central Madichuk Clinic, Goyang, Korea

Objective: We propose that cervical intrafacetal fusion (cIFF) using bone chip insertion into the facetal joint space additional to minimal PLF is a supplementary fusion method to conventional posterolateral fusion (PLF).
Methods: Patients who underwent posterior cervical fixation accompanied by cIFF with minimal PLF or conventional PLF for cervical myelopathy from 2012 to 2023 were investigated retrospectively. Radiological parameters including Cobb angle and C2–7 sagittal vertical axis (SVA) were compared between the 2 groups. In cIFF with minimal PLF group, cIFF location and PLF location were carefully divided, and the fusion rates of each location were analyzed by computed tomography scan.
Results: Among enrolled 46 patients, 31 patients were in cIFF group, 15 in PLF group. The postoperative change of Cobb angle in 1-year follow-up in cIFF with minimal PLF group and conventional PLF group were 0.1° ± 4.0° and -9.7° ± 8.4° respectively which was statistically lower in cIFF with minimal PLF group ($p = 0.022$). Regarding the fusion rate in cIFF with minimal PLF group in postoperative 6 months, the rates was achieved in 267 facets (98.1%) in cIFF location, and 244 facets (89.7%) in PLF location ($p < 0.001$).
Conclusion: Postoperative sagittal alignment was more preserved in cIFF with minimal PLF group compared with conventional PLF group. Additionally, in cIFF with minimal PLF group, the bone fusion rate of cIFF location was higher than PLF location. Considering the concerns of bone chip migration onto the spinal cord and relatively low fusion rate in PLF method, applying cIFF method using minimized PLF might be a beneficial alternative for posterior cervical decompression and fixation.

Keywords: Intrafacetal fusion, Posterolateral fusion, Posterior cervical fusion

INTRODUCTION

Posterior cervical fusion (PCF) is an important method for degenerative cervical spine disease, cervical ossification of posterior longitudinal ligament (OPLL), cervical trauma and tumor disease. Historically, PCF was developed at the beginning of the 20th century from the methods of Hibbs[1] and Albee[2] who used only an autologous bone graft. Following the description of the wiring technique by Rogers[3] in 1942, new methods such as translaminar screws, lateral mass screws (LMS), and pedicle screws were introduced.[4-12] These instrumentations provide immediate stability, and patients benefit from earlier mobilization and rehabilitation while waiting for bone fusion. However, long-term stabilization through instrumental fixation should achieve final bone fusion such as posterolateral fusion (PLF) and proper preparation of the fusion bed is inevitable. However, conventional PLF has some disadvantages including bone chip migration to the spinal cord, which is exposed for decompression, posterior neck pain due to far lateral muscle detachment to make a sufficient fusion bed, or poor fusion rate due to bone chip resorption which has only been reported to be approximately 60%–80%.[13-15] Another procedure for PCF is cervical intrafacetal fusion (cIFF) using bone chip insertion into well-dissected and prepared facetal joint spaces. Therefore, cIFF technique added with minimal PLF could prevent disadvantage of conventional PLF and increase bone fusion rate; however, this is not currently common in cervical spine surgery. In this study, we hypothesized that cIFF achieves a higher rate of bone fusion compared to cervical PLF and demonstrated that adding cIFF to minimal PLF helps maintain cervical alignment and promotes bone fusion.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board (IRB) of Asan Medical Center (IRB No. 2023-1087), ensuring compliance with ethical standards. Given the retrospective nature of the study, the requirement for informed consent was waived by the IRB.

1. Study Design

In this single-center study, patients who underwent posterior cervical laminectomy and screw fixation accompanied by cIFF with minimal PLF and conventional PLF for cervical myelopathy from March 2012 to December 2023 were investigated retrospectively. Among 179 patients, 46 patients were finally selected for the study: 15 patients had posterior cervical fixation accompanied by conventional PLF and 31 patients had cIFF with minimal PLF. Inclusion criteria were a diagnosis of degenerative cervical myelopathy or OPLL. Exclusion criteria consisted of (1) fusion level equal to or less than 2, (2) fusion including occipito-cervical or C1 level, (3) cervical spine tumor, (4) infectious disease, (5) congenital disease, (6) traumatic spine disease, (7) patients followed-up for less than 6 months.

2. Surgical Procedure of cIFF With Minimal PLF

The patient was placed in a prone position with the head secured in a 3-point Mayfield skull clamp (Integra Life Science Corporation, Cincinnati, OH, USA). A midline skin incision was conducted. For visualization of the LMS insertion point, paravertebral muscles were dissected to the lateral margin of the lateral mass. Bilateral gutters were made to remove the lamina for cord decompression using high-speed drilling (Fig. 1A). Then, the lamina was removed *en bloc* to minimize spinal cord damage (Fig. 1B–D). Drilling with 2- and 3-mm diamond burs was performed to widen the facetal cavity (Fig. 1E, F). Next, curettage was conducted for the meticulous decortication of the intrafacetal space (Fig. 1G, H). In this step, to avoid ventral penetration beyond the facetal space, drilling was kept within a 10-mm depth. Then, bone chips harvested from the removed lamina were inserted into the intrafacetal space using a small impactor (Fig. 1I, J). Afterwards, 2 different screw insertion techniques were used according to the targeted surgical areas: LMS was applied for C3 to C6, and a cervical pedicle screw was used for C2, C7, and T1. Alternatively, for small lateral masses, a pedicle screw was inserted. After cervical screws were inserted, rods were placed and tightened. Remaining bone chips mixed with demineralized bone materials were applied along the lateral side of the lateral mass, which was decorticated for PLF. However, the volume of bone chips for PLF was applied limitedly to avoid bone chip migration onto the spinal cord, and lateral surface decortication in lateral mass was not performed to avoid postoperative neck pain which we named minimal PLF. Finally, muscles and skin were closed tightly. The patient was instructed to wear a Philadelphia collar (Ossur Orthopedics, Reykjavik, Iceland) for 5 months after the surgery for solid bone fusion and a computed tomography (CT) scan was conducted to assess whether bone fusion had been achieved at the 6 months after surgery.

3. Clinical and Radiological Analysis

The patients were divided into 2 groups, conventional PLF group and cIFF with minimal PLF group, and patients' medical and radiographical records were reviewed. Clinical outcomes were assessed by examining the changes in Nurick grades before and after the surgery. Radiological parameters including C2–7 Cobb angle and C2–7 sagittal vertical axis (SVA) were measured preoperatively, immediate postoperatively, and at the 1-year follow-up.

In cIFF with minimal PLF group, cIFF location and PLF location were divided, and the fusion rates of each location were

https://doi.org/10.14245/ns.2347132.566

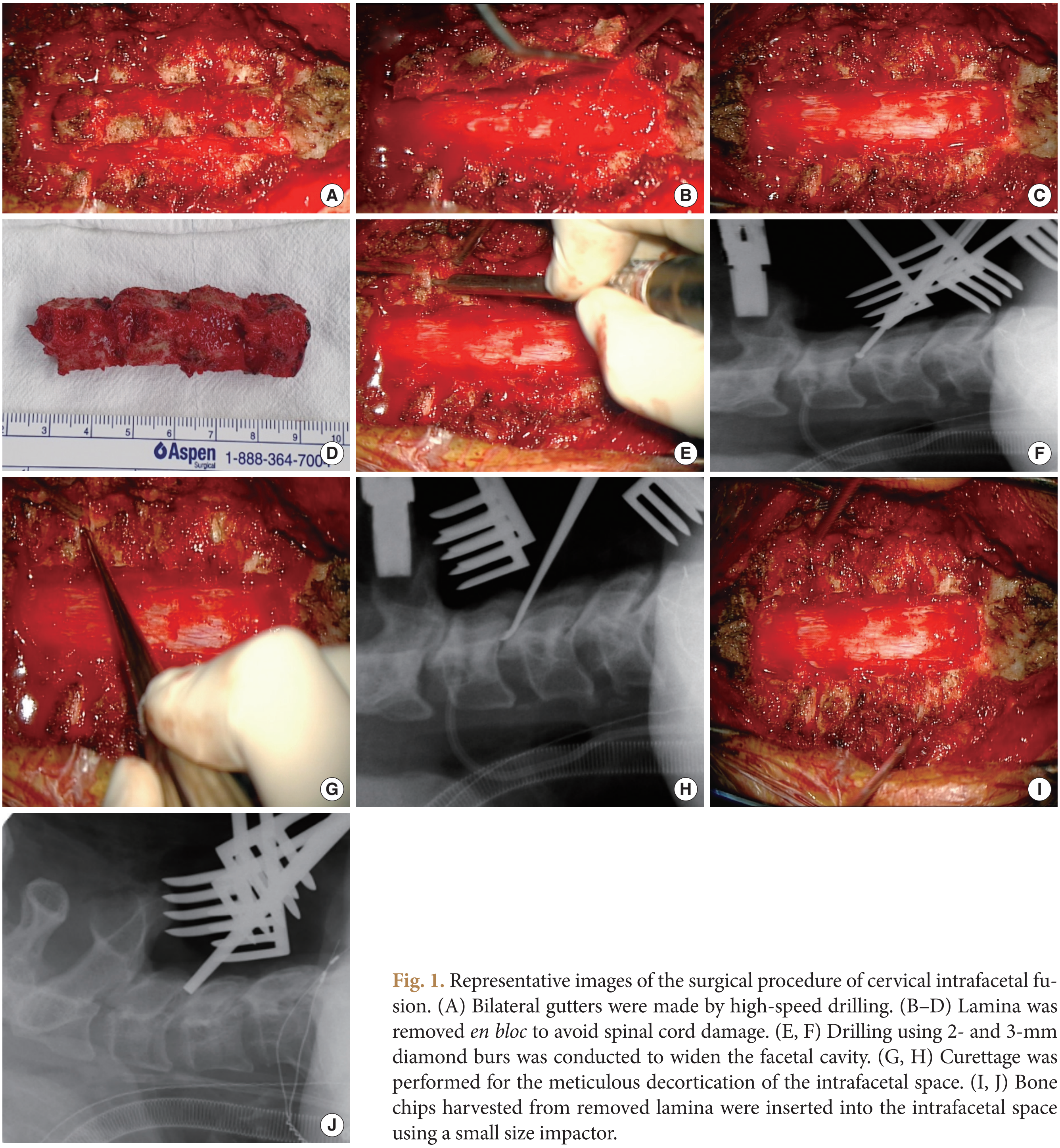

Fig. 1. Representative images of the surgical procedure of cervical intrafacetal fusion. (A) Bilateral gutters were made by high-speed drilling. (B–D) Lamina was removed *en bloc* to avoid spinal cord damage. (E, F) Drilling using 2- and 3-mm diamond burs was conducted to widen the facetal cavity. (G, H) Curettage was performed for the meticulous decortication of the intrafacetal space. (I, J) Bone chips harvested from removed lamina were inserted into the intrafacetal space using a small size impactor.

compared in postoperative 6 months. The achievement of fusion was decided by the presence of trabecular bone bridging on a CT scan. To analyze the successful fusion, the fusion bridge was carefully evaluated at each facetal level. The first step was examination of the CT sagittal image to determine whether IFF or PLF had occurred. This evaluation was performed by drawing the facet outline (Fig. 2A, B) and identifying a direct bone bridge inside the facet joint was decided to intrafacetal fusion, whereas a circumferential fusion bridge outside the facet joint was considered as evidence of PLF (Fig. 2C, D). If a direct bone bridge was not observed at a specific level, the CT coronal image at that same level was examined (Fig. 2E, F). The levels in

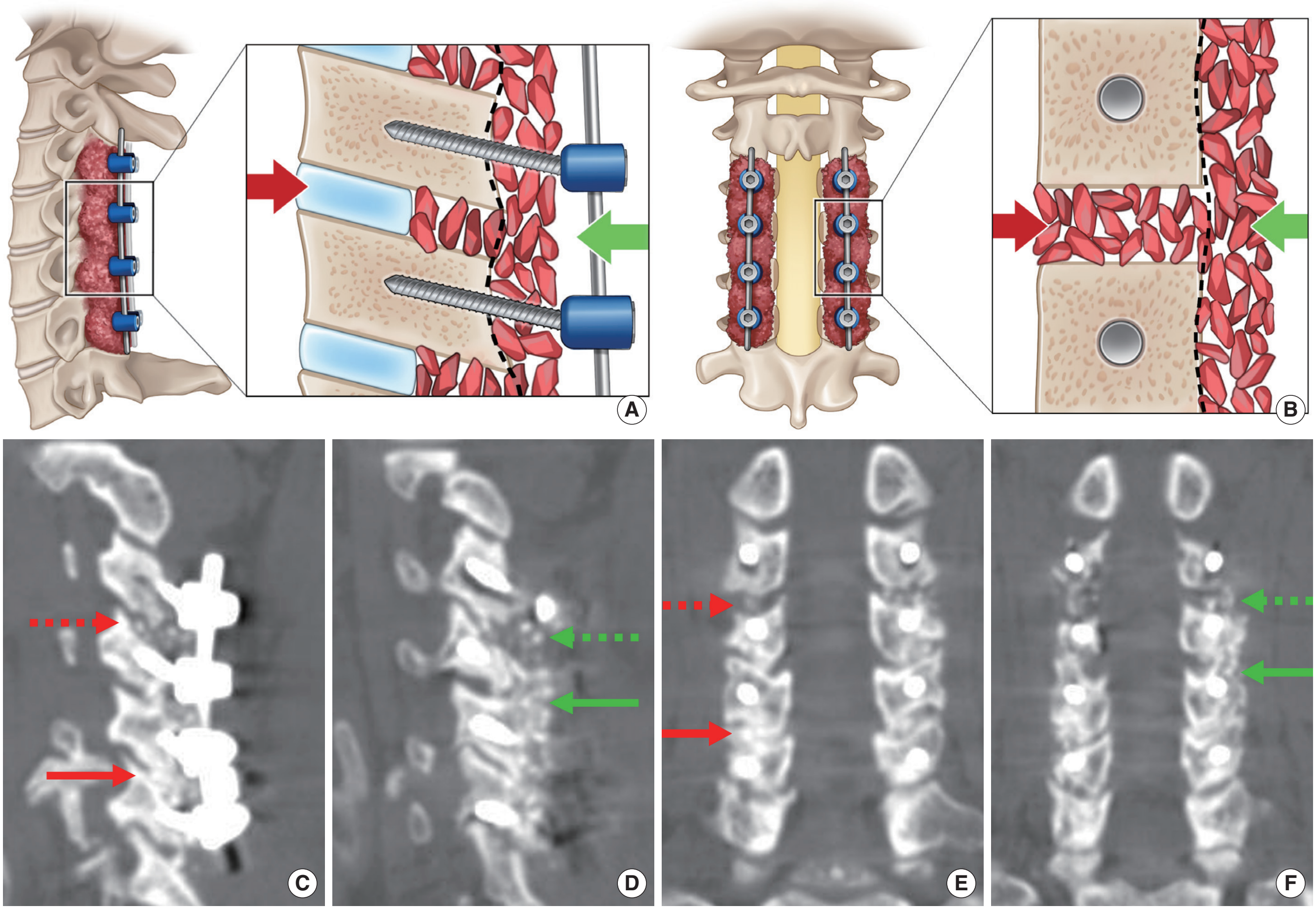

Fig. 2. Evaluation methods of fusion by computed tomography (CT). Drawing the line between the facet and posterolateral area around facet. (A, B) In cIFF, the facets which showed bone bridges and continuity in the intrafacetal space (indicated by a red arrow) were counted as successful fusion, and in PLF, the facets which showed bone bridges and continuity around the facet surface (indicated by a green arrow) were counted as successful fusion. Unsuccessful cIFF at the C3–4 level (indicated by a red dotted arrow) and successful cIFF at the C5–6 level (indicated by a red solid arrow) are shown on midfacetal sagittal CT (C) and coronal CT (E) images. Unsuccessful PLF at the C3–4 level (indicated by a green dotted arrow) and successful PLF at the C4–5 level (indicated by a green solid arrow) are more lateral sagittal (D) and more dorsal coronal (F) than the midfacetal line CT image.

which the CT sagittal and coronal images showed no direct bone bridge were classified as nonfusion.

4. Statistics

The simple t-test and paired t-test were conducted using IBM SPSS Statistics ver. 20.0 (IBM Co., Armonk, NY, USA) to assess preoperative and postoperative parameters and fusion mass. Statistical significance was set at $p < 0.05$.

RESULTS

1. Demographics

The demographic data of the enrolled patients is presented in Table 1. The 46 patients included 31 males (67%) and 15 females (33%), with a mean age at surgery of 63.4 years (range, 38–85 years). The average clinical follow-up was 19.5 months (range, 6–106 months). In cIFF with minimal PLF group, 6 patients had pedicle screws instead of LMS in the segment of the small lateral mass between C3 and C6 levels. Two patients experienced wound dehiscence from superficial infection. Among them, 1 patient underwent a revision procedure and 1 patient received hyperbaric oxygen therapy without revision. During the screw insertion procedure, 1 patient experienced a vertebral artery injury when trying to insert the pedicle screw, and then, this was converted to LMS. Two patients developed C5 palsy: in 1 patient, this was caused by the ventral extrafacetal impaction of a bone chip into the neural foramen, and they underwent revision surgery to remove the bone chip, resulting in a

 https://doi.org/10.14245/ns.2347132.566

Table 1. Summary of demographic data obtained in enrolled patients

No.	Age (yr)	Sex	Diagnosis	Operation	Nurick score		Follow-up duration (mo)	BMD	Fusion level	Screw other than routine	Complications
					Preop	Last					
1	60	M	OPLL	cIFF with minimal PLF	2	1	7	2.1	C3–6		Delayed C5 palsy (4 days after discharge)
2	66	M	CSM		3	2	10	1.5	C3–6		
3	53	M	CSM		1	1	8	-0.2	C3–7		
4	57	M	OPLL		1	1	6	-0.2	C3–7		
5	57	F	CSM		1	1	8	-2.4	C2–T1		
6	70	F	CSM		2	1	10	-0.9	C3–T1		
7	64	M	CSM		2	1	8	0.8	C2–7		
8	41	M	OPLL		1	1	10	-0.3	C3–7		
9	38	M	OPLL		2	1	7	-2.2	C2–7		
10	78	F	CSM		4	3	12	-0.6	C4–7	CPS at left C4	
11	60	M	OPLL		1	1	11	0.5	C2–6	CPS at C6 bilateral	
12	61	F	OPLL		1	1	7	-0.5	C2–7		
13	61	M	OPLL		2	-	6	-0.4	C3–6	CPS at right C3, 4, 5	Wound infection
14	69	M	OPLL		2	1	6	1.1	C2–6	CPS at right C6	
15	68	M	OPLL		2	1	7	3.5	C2–T1		
16	66	M	OPLL		1	1	6	0.5	C2–7		
17	58	F	OPLL		3	2	11	-1.3	C2–7		
18	82	M	CSM		4	3	6	-2.2	C3–7		
19	53	M	CSM		2	1	6	-1.3	C3–6	CPS at right C3, 4, 5, 6	C5 palsy due to bone chip migration
20	55	M	OPLL		2	1	6	-1	C2–7		
21	62	M	OPLL		1	1	25	-1.1	C3–7		
22	48	F	OPLL		2	1	6	1	C2–7		Wound dehiscence (only hyperbaric oxygen therapy)
23	57	M	OPLL		1	1	7	-	C3–7	CPS at left C3, 4	
24	68	F	CSM		3	3	20	-2.2	C3–7		Vertebral artery injury
25	77	M	CSM		3	-	6	-2.9	C3–7		
26	55	F	CSM		2	1	17	-0.3	C3–T4		
27	75	M	CSM		3	2	11	0.8	C2–7		
28	85	M	CSM		3	2	16	-0.9	C2–6		
29	66	F	CSM		1	-	49	-1.6	C3–T1		
30	53	M	OPLL		1	1	42	-0.7	C3–7		

(*Continued*)

Table 1. Summary of demographic data obtained in enrolled patients (Continued)

No.	Age (yr)	Sex	Diagnosis	Operation	Nurick score		Follow-up duration (mo)	BMD	Fusion level	Screw other than routine	Complications
					Preop	Last					
31	53	F	CSM		4	3	16	-0.9	C3–6		
32	64	F	OPLL	Conventional PLF	2	1	36	-1.5	C2–6	CPS at right C3, 4, 5, 6	
33	60	M	CSM		2	2	40	0.9	C2–5	CPS at right C3, 4 and bilat, C5	
34	61	M	CSM		4	2	13	-	C3–7	CPS at bilat C3 and right C5	
35	58	F	OPLL		2	3	42	-0.6	C2–T2	CPS at right 4, 5	Postop hematoma with revision surgery
36	69	M	OPLL		2	1	12	2.1	C2–5	CPS at bilat C5	
37	78	F	CSM		2	2	12	-3.4	C3–7	CPS at bilat C3, right C4, left C5, 6	
38	69	M	OPLL		2	2	35	0.5	C2–5	CPS at left C5	
39	66	M	OPLL		4	3	36	-	C4–7	CPS at right C4, 5, 6	
40	60	M	CSM		2	2	12	-0.1	C4–7	CPS at bilat C4, 6, right C5	
41	71	M	CSM		2	1	12	-1	C2–5	CPS at right C4, bilat C5	
42	71	F	OPLL		2	1	12	-2	C2–7	CPS at right C3, 4, 6 and translaminar screw, left C2	
43	78	M	CSM		3	2	12	-1	C3–7	CPS at bilat C5, 6	
44	73	M	CSM		1	1	59	-0.3	C4–7		
45	58	M	CSM		2	2	106	-	C4–T2		
46	67	F	CSM		2	1	36	-2.5	C4–T1	CPS at bilat C4, 5, 6	

BMD, bone marrow density; OPLL, ossification of posterior longitudinal ligament; CSM, cervical spondylotic myelopathy; cIFF, cervical intrafacetal fusion; PLF, posterolateral fusion; CPS, cervical pedicle screw; bilat, bilateral.

https://doi.org/10.14245/ns.2347132.566

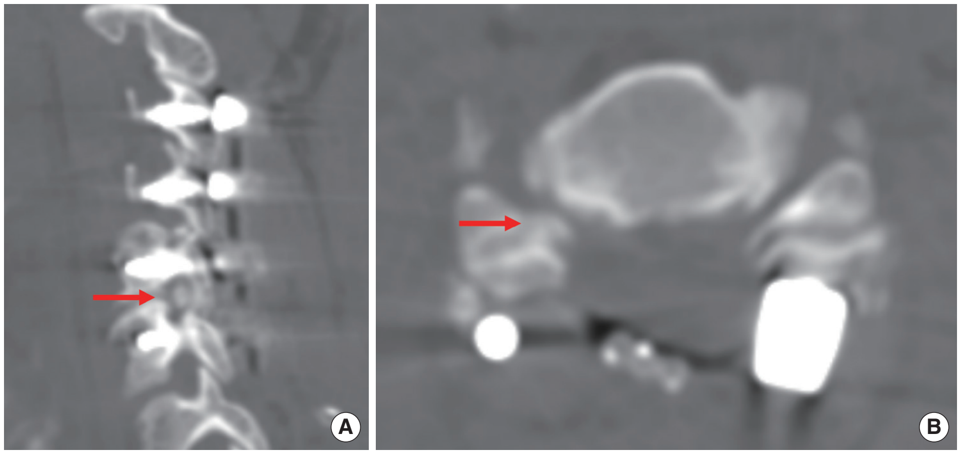

Fig. 3. The ventral extrafacetal impaction of a bone chip into the neural foramen (indicated by a red arrow), causing compression of the C5 nerve root is shown on sagittal (A) and axial computed tomography images (B).

gradual recovery of motor function (Fig. 3A, B). The other C5 palsy was of unknown origin and recovered spontaneously. In conventional PLF group, 13 patients had pedicle screws instead of LMS in the selected segment dependent on surgeon's decision. One patient underwent a revision surgery due to postoperative hematoma.

The comparison of demographic data between cIFF with minimal PLF group and conventional PLF group is presented in Table 2. In cIFF with minimal PLF group, 15 patients were diagnosed with CSM, and 16 patients were diagnosed with OPLL. In conventional PLF group, 9 patients were diagnosed with CSM, and 6 patients were diagnosed with OPLL. The Nurick score improvement after operation was 0.55 ± 0.49 in cIFF with minimal PLF group which was significantly lower than conventional PLF group (0.53 ± 0.71, $p = 0.040$). In cIFF with minimal PLF group, the mean bone marrow density (BMD) was -0.41 ± 1.39 and in conventional PLF group, BMD was -0.74 ± 1.45. In all patients, 7 patients had osteopenia, and 3 had osteoporosis. However, all osteopenia and osteoporosis patients did not receive any additional medications for osteoporosis.

2. Comparison of Cervical Parameters Between Selected cIFF With Minimal PLF Group and Conventional PLF Group

Comparison of cervical parameters of preoperative, postoperative, 1-year follow-up, and postoperative change (1-year follow-up – immediate postoperative) between cIFF with minimal PLF group and conventional PLF group is presented in Table 3. Among 31 patients of cIFF with minimal PLF group, 16 patients whose follow-up period was above 1-year were selected and sagittal parameter was calculated. The average Cobb angle before surgery for the patients was 10.5° ± 10.0° and 8.6° ± 8.2° in immediate postoperative and 8.8° ± 7.6° in 1-year follow-up. In conventional PLF group, the average Cobb angle before surgery

Table 2. Comparison of demographic data between cIFF with minimal PLF group and conventional PLF group

Variable	cIFF with minimal PLF group (n = 31)	Conventional PLF group (n = 15)	p-value
Age	61.8 ± 10.7	66.8 ± 6.4	0.117
Sex			
Male	21 (67)	10 (66)	0.888
Female	10 (33)	5 (34)	
Diagnosis			
CSM	15 (48)	9 (60)	0.298
OPLL	16 (52)	6 (40)	
Nurick score			
Preoperative (pre)	2.03 ± 0.97	2.26 ± 0.77	0.301
Postoperative (post)	1.43 ± 0.73	1.73 ± 0.68	0.803
ΔPost–pre	-0.55 ± 0.21	-0.53 ± 0.71	0.040*
Follow-up (mo)	13.6 ± 10.2	31.6 ± 24.7	0.004*
BMD	-0.41 ± 1.39	-0.74 ± 1.45	0.975
Fusion level			
3	6 (19)	7 (47)	0.900
4	12 (39)	5 (33)	
5	10 (32)	2 (13)	
≥ 6	3 (10)	1 (7)	

Values are presented as mean ± standard deviation or number (%).
cIFF, cervical intrafacetal fusion; PLF, posterolateral fusion; CSM, cervical spondylotic myelopathy; OPLL, ossification of posterior longitudinal ligament; BMD, bone mineral density.
*$p < 0.05$, statistically significant differences.

Table 3. Comparison of cervical parameters of preoperative, immediate postoperative, 1-year follow-up, and Δ (1-year follow-up – immediate postoperative) between cIFF with minimal PLF group and conventional PLF group

Variable	cIFF with minimal PLF group (n = 16)	Conventional PLF group (n = 15)	p-value
Cobb angle (°)			
Preoperative	10.5 ± 10.0	16.3 ± 7.2	0.080
Postoperative	8.6 ± 8.2	13.3 ± 8.4	0.784
1-Year follow-up	8.8 ± 7.6	3.7 ± 8.8	0.677
Δ (1-Year F/U–postoperative)	0.1 ± 4.0	-9.7 ± 8.4	0.022*
C2–7 SVA			
Preoperative	34.8 ± 18.9	29.8 ± 13.8	0.369
Postoperative	36.2 ± 12.3	32.5 ± 13.2	0.951
1-Year follow-up	34.5 ± 15.3	42.6 ± 20.3	0.466
Δ (1-Year F/U–postoperative)	-1.7 ± 10.5	10.0 ± 16.7	0.430

Values are presented as mean ± standard deviation.
cIFF, cervical intrafacetal fusion; PLF, posterolateral fusion; F/U, follow-up; SVA, sagittal vertical axis.
*p < 0.05, statistically significant differences.

was 16.3° ± 7.2° and 13.3° ± 8.4° in immediate postoperative and 3.7° ± 8.8° in 1-year follow-up. The change (1-year follow-up – immediate postoperative) in cIFF with minimal PLF group was 0.1° ± 4.0° which was significantly lower than conventional PLF group (-9.7° ± 8.4°, p = 0.022). In the cIFF with minimal PLF group, the average C2–7 SVA before surgery for the patients was 34.8 ± 18.9 and 36.2 ± 12.3 in immediate postoperative and 34.5 ± 15.3 in 1-year follow-up. In conventional PLF group, the average C2–7 SVA before surgery was 29.8 ± 13.8 and 32.5 ± 13.2 in immediate postoperative and 42.6 ± 20.3 in 1-year follow-up. The change (1-year follow-up – immediate postoperative) in cIFF with minimal PLF group was -1.7 ± 10.5 which was not significant but lower than conventional PLF group (10.0 ± 16.7, p = 0.430).

3. Comparison of Fusion Rate According to cIFF and PLF Locations in cIFF With Minimal PLF Group

In cIFF with minimal PLF group, cIFF location and PLF location were divided and the fusion rates of each location in postoperative 6 months were carefully compared (n = 31). The total number of facets among the cIFF with minimal PLF group was 272. Among them, fusion success in cIFF location was observed in 267 facets (98.1%), and in PLF location, 244 facets (89.7%) were successful, which was significantly different (p < 0.001).

Table 4. Comparison of the fusion rate between cIFF location and PLF location in cIFF with minimal PLF group after 6 months

Fusion level	cIFF	PLF	p-value
C2–3 (n = 30)	28 (93.3)	22 (73.3)	0.038*
C3–4 (n = 58)	57 (98.2)	49(84.4)	0.008*
C4–5 (n = 60)	60 (100)	59 (98.3)	0.315
C5–6 (n = 60)	60 (100)	58 (96.6)	0.154
C6–7 (n = 46)	45 (97.8)	40 (86.9)	0.049*
C7–T1 (n = 12)	11 (91.6)	10 (83.3)	0.537
T1–2 (n = 2)	2 (100)	2 (100)	1.000
T2–3 (n = 2)	2 (100)	2 (100)	1.000
T3–4 (n = 2)	2 (100)	2 (100)	1.000
Total (n = 272)	267 (98.1)	244 (89.7)	< 0.001*

Values are presented as number (%).
cIFF, cervical intrafacetal fusion; PLF, posterolateral fusion.
*p < 0.05, statistically significant differences.

When analyzed by level, the fusion rate of cIFF in C2–3, 3–4, and 6–7 was significantly higher than that of PLF (Table 4).

DISCUSSION

In the situation where wide cervical laminectomy for spinal cord decompression is performed, placing bone chips around a decorticated lateral mass for PLF can potentially induce the migration of bone chips onto the spinal cord, resulting in unfortunate spinal cord compression. The concerns of bone chip migration make it insufficient for the application of bone chips in the PLF bed.[13,14] Moreover, the bone fusion rate at the area treated with PLF was reported to be approximately 60%–90% and tended to be poorly fused where preoperative instability was found.[16-22] Additionally, extensive lateral muscle dissection to create a PLF bed provokes uncomfortable postoperative neck pain.[13,14] Therefore, we utilized a technique that involves the direct placing of bone chips into the intrafacetal space to induce cIFF, which applies as additional methodology to limited PLF to overcome the disadvantages of PLF alone. When we conduct cIFF combined with minimal PLF, it is possible to perform less invasive PLF as an adjuvant procedure by applying a small volume of bone chips as well as less lateral muscle detachment and avoiding lateral surface decortication of lateral mass. After removing the soft tissue within the intrafacetal space and utilizing the autologous bone chips obtained during laminectomy, we can safely and conveniently impact bone chips without concerns of their migration towards the spinal cord. Because the

 https://doi.org/10.14245/ns.2347132.566

bone chips are fixed within the intrafacetal tight space, they are expected to promote effective bone fusion. Intrafacetal fusion, unlike onlay grafts that performed in PLF, is expected to allow a higher rate of direct fusion considering the transmission of axial loading and Wolff's law.[23]

There have been a few reports of the intrafacetal technique in PCF. Cofano et al.[24] reported the insertion of cervical interfacetal spacer allograft during PCF in patients who had developed pseudarthrosis after anterior cervical discectomy and fusion. The paper suggested that the fusion rate could be improved, and foraminal stenosis could be addressed by increasing the foraminal height and width. However, their study targeted patients who had undergone the anterior approach. Although Kansal et al.[25] used the terminology of intrafacetal fusion in bilateral C1–2 transarticular screw insertion, this was approached by anterior high cervical retropharyngeal approach. Therefore, this present study is the first report to address intrafacetal fusion in the posterior approach of a general degenerative cervical spine and OPLL. In the previous reports, the terminology "intrafacetal" and "interfacetal" were intermingled, but we considered "intrafacetal" might be more appropriate terminology to describe a fusion method that inserts bone chips into the cervical facetal space.

Based on the data, when comparing the follow-up results on the sagittal alignment of cIFF with minimal PLF group and conventional PLF group, it was noted that the Cobb angle and C2–7 SVA were observed as having better maintenance in lordotic curve during the follow-up in cIFF with minimal PLF group rather than conventional PLF group. In comparison with previous study using LMS fixation with PLF only, this result of present study showed better outcome. Lee et al.[10] reported the difference of Cobb angle between final follow-up and immediate postoperative was -0.70° after LMS with PLF only, which is higher in postoperative loss of lordotic curve than our results (0.1° ± 4.0°). And, in C2–7 SVA, the difference between final follow-up and immediate postoperative was 2.06 which higher than our results (-1.7 ± 10.5). Inose et al.[26] documented alterations in cervical lordosis after posterior cervical decompression and PLF between preoperative and postoperative 1-year results which were 9.9° ± 11.3° and 4.6° ± 10.4°. Additionally, the C2–7 SVA from 21.8 ± 20.2 to 29.3 ± 20.2. Comparing to our preoperative and postoperative 1 year data of cIFF with minimal PLF group, in which the preoperative Cobb angle was 10.5° ± 10.0° and reduced to 8.8° ± 7.6° 1 year postoperative, and the C2–7 SVA measured 34.8 ± 18.9 preoperatively and 34.5 ± 15.3 1 year postoperatively, the present novel technique demonstrated a better preservation of cervical sagittal alignment.

The previous literatures which studied about PCF rates used dynamic x-ray and the absence of instability was used as the indication of fusion.[9,16-18,27-31] Highsmith et al.[18] reported a fusion rate of 92% in 24 months and Heller et al.[21] 61.5% in 25.5 months in which they used absence of pseudoarthrosis in simple x-ray as a criteria of fusion. However, Hong et al.[9] reported 100% of fusion in 18.9 months. Therefore, the evaluation of fusion by simple x-ray has a variable range of fusion rate. In our study, the CT scan observing bone bridge or trabecular bone formation enabled a more objective comparison of fusion rates by directly evaluating the cIFF location and PLF location in the fusion bed in patients and we evaluated them in relatively early follow-up period than previous studies. In cIFF with minimal PLF group, when counting the number of fused facets in cIFF location, the fusion rate 98.1% in 6 months was significantly higher when compared to PLF location (89.7%, $p < 0.001$). Because of the minimal PLF procedure leading to a relatively small fusion bed space due to limited muscle dissection and the use of fewer bone chips, the lower fusion rate observed may be attributed to these factors. However, at just 6 months postoperative state, the cIFF demonstrated a significantly higher fusion rate of 98.1%, suggesting it a promising option to improve the fusion success in PCF surgery. The locations of the worse facet fusion rate in PLF compared to cIFF were C2–3, C3–4, and C6–7 levels, which is supposed to be the results of micromotion in the uppermost and lowermost portion of the cervical region. Therefore, the need of cIFF is emphasized in these levels.

In cIFF with minimal PLF group, C5 palsy was observed in 2 cases postoperatively, and in one of them, we considered it was caused by bone chips which were deeply inserted and penetrated beyond ventral facetal surface resulting in nerve root compression. The penetrated bone chips were confirmed on postoperative CT. Therefore, we performed a revision procedure to remove the penetrated bone chips. The patient recovered gradually from C5 palsy during the 19-month follow-up. It is important to note that during cIFF procedures, there might be a risk of nerve root or vertebral artery compression from the penetration of bone chips beyond the ventral facetal margin. This complication could be prevented by avoiding drilling more than 10-mm depth from the dorsal facet surface and aggressive bone chip impaction during cIFF.

This study had several limitations. First, the retrospective design of the present study might have the potential selection bias and limited data; therefore, we need to perform a more precise study design such as prospective study including patient-reported outcomes with Japanese Orthopaedic Association score or visual analogue scale score to demonstrate the advantage of cIFF compared to PLF. Second, the data of fusion rate did not directly compare cIFF and PLF using double-arm study. Instead, we analyzed fusion results based on patients who underwent both procedures simultaneously, making an independent comparison difficult. Third, the comparison of fusion rates at the 6 months postoperatively may not have shown sufficient fusion. Comparing the long-term follow-up CT-based fusion rates with the conventional PLF group, would provide a more accurate analysis. Fourth, factors that can influence fusion outcomes, such as BMD and types of screw fixation were not taken into consideration: in cIFF with minimal PLF group, pedicle screws were inserted in 6 patients (19%) because of a small lateral mass between the C3 and C6 levels, and in conventional PLF group, pedicle screws were inserted in 13 patients (86%) because of surgeon's preference. Finally, the cases enrolled in this study were chosen with a specific focus on degenerative spine conditions and OPLL. Further validation in extended indications, for example trauma or spine metastasis, is required to determine the effectiveness of cIFF.

CONCLUSION

In this study, to overcome the limitations of PLF, which has a relatively lower fusion rate, risks of bone chip migration to the spinal cord, and can induce neck pain due to wide muscle dissection and extended decortication, we introduced an alternative technique that directly inserts bone chips into the intrafacetal space combined with minimal PLF. Postoperative sagittal alignment was more preserved in cIFF with minimal PLF group rather than conventional PLF group. The fusion rate according to location, intrafacetal space (98.1%) was significantly higher than PLF bed (89.7%) in cIFF with minimal PLF technique. Considering the concerns of disadvantages in the PLF procedure as well as the convenience of the intrafacetal fusion technique, the additional cIFF combined with minimal PLF might be a beneficial alternative for posterior cervical decompression and fixation.

NOTES

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This research was supported by the Korean Fund for Regenerative Medicine (KFRM) grant funded by the Korea government (the Ministry of Science and ICT, the Ministry of Health & Welfare) (No. 23C0120L1).

Author Contribution: Conceptualization: SRJ; Formal analysis: SWJ; Investigation: SWJ; Methodology: SWJ, SRJ; Project administration: SRJ; Writing – original draft: SWJ; Writing – review & editing: SWJ, SHL, JKJ, HKS, JHP, SRJ, SWR.

ORCID

Sun Woo Jang: 0000-0001-8425-4961
Sang Hyub Lee: 0000-0002-6642-5285
Jeong Kyun Joo: 0000-0002-5722-1213
Hong Kyung Shin: 0000-0001-8182-3321
Jin Hoon Park: 0000-0002-0903-3146
Sung Woo Roh: 0000-0001-6562-4154
Sang Ryong Jeon: 0000-0002-8340-7978

REFERENCES

1. Hibbs RA. An operation for progressive spinal deformities: a preliminary report of three cases from the service of the orthopaedic hospital. 1911. Clin Orthop Relat Res 2007; 460:17-20.
2. Albee FH. Transplantation of a portion of the tibia into the spine for Pott's disease: a preliminary report 1911. Clin Orthop Relat Res 2007;460:14-6.
3. Rogers WA. Fractures and dislocations of the cervical spine; an end-result study. J Bone Joint Surg Am 1957;39-A:341-76.
4. Denaro V, Di Martino A. Cervical spine surgery: an historical perspective. Clin Orthop Relat Res 2011;469:639-48.
5. Callahan RA, Johnson RM, Margolis RN, et al. Cervical facet fusion for control of instability following laminectomy. J Bone Joint Surg Am 1977;59:991-1002.
6. Anderson PA, Henley MB, Grady MS, et al. Posterior cervical arthrodesis with AO reconstruction plates and bone graft. Spine (Phila Pa 1976) 1991;16(3 Suppl):S72-9.
7. Anderson PA, Matz PG, Groff MW, et al. Laminectomy and fusion for the treatment of cervical degenerative myelopathy. J Neurosurg Spine 2009;11:150-6.
8. Coe JD, Vaccaro AR, Dailey AT, et al. Lateral mass screw fixation in the cervical spine: a systematic literature review. J Bone Joint Surg Am 2013;95:2136-43.
9. Hong JT, Yi JS, Kim JT, et al. Clinical and radiologic outcome of laminar screw at C2 and C7 for posterior instrumentation--review of 25 cases and comparison of C2 and C7 intralaminar screw fixation. World Neurosurg 2010;73:112-8; discussion e15.
10. Lee S, Cho DC, Roh SW, et al. Cervical alignment following

 https://doi.org/10.14245/ns.2347132.566

posterior cervical fusion surgery: cervical pedicle screw versus lateral mass screw fixation. Spine (Phila Pa 1976) 2021;46:E576-83.

11. Mikhail CM, Dowdell JE 3rd, Hecht AC. Posterior fusion for the subaxial cervical spine: a review of the major techniques. HSS J 2020;16:188-94.
12. Zaveri GR, Jaiswal NP. A comparison of clinical and functional outcomes following anterior, posterior, and combined approaches for the management of cervical spondylotic myelopathy. Indian J Orthop 2019;53:493-501.
13. Shin HK, Kim M, Oh SK, et al. Posterior thoracic cage interbody fusion offers solid bone fusion with sagittal alignment preservation for decompression and fusion surgery in lower thoracic and thoracolumbar spine. J Korean Neurosurg Soc 2021;64:922-32.
14. Kim M, Oh SK, Choi I, et al. Clinical outcomes of posterior thoracic cage interbody fusion (PTCIF) to treat trauma and degenerative disease of the thoracic and thoracolumbar junctional spine. J Clin Neurosci 2019;60:117-23.
15. Hamanishi C, Tanaka S. Bilateral multilevel laminectomy with or without posterolateral fusion for cervical spondylotic myelopathy: relationship to type of onset and time until operation. J Neurosurg 1996;85:447-51.
16. Miyazaki K, Tada K, Matsuda Y, et al. Posterior extensive simultaneous multisegment decompression with posterolateral fusion for cervical myelopathy with cervical instability and kyphotic and/or S-shaped deformities. Spine (Phila Pa 1976) 1989;14:1160-70.
17. Dorward IG, Buchowski JM, Stoker GE, et al. Posterior cervical fusion with recombinant human bone morphogenetic protein-2: complications and fusion rate at minimum 2-year follow-up. Clin Spine Surg 2016;29:E276-81.
18. Highsmith JM, Dhall SS, Haid RW Jr, et al. Treatment of cervical stenotic myelopathy: a cost and outcome comparison of laminoplasty versus laminectomy and lateral mass fusion. J Neurosurg Spine 2011;14:619-25.
19. Yoon ST, Hashimoto RE, Raich A, et al. Outcomes after laminoplasty compared with laminectomy and fusion in patients with cervical myelopathy: a systematic review. Spine (Phila Pa 1976) 2013;38(22 Suppl 1):S183-94.
20. Chen Y, Guo Y, Lu X, et al. Surgical strategy for multilevel severe ossification of posterior longitudinal ligament in the cervical spine. J Spinal Disord Tech 2011;24:24-30.
21. Heller JG, Edwards CC 2nd, Murakami H, et al. Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: an independent matched cohort analysis. Spine (Phila Pa 1976) 2001;26:1330-6.
22. Lee CH, Lee J, Kang JD, et al. Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: a meta-analysis of clinical and radiological outcomes. J Neurosurg Spine 2015;22:589-95.
23. Anand N. Overview of biologics. Spine (Phila Pa 1976) 2016;41 Suppl 7:S10.
24. Cofano F, Sciarrone GJ, Pecoraro MF, et al. Cervical interfacet spacers to promote indirect decompression and enhance fusion in degenerative spine: a review. World Neurosurg 2019;126:447-52.
25. Kansal R, Sharma A, Kukreja S. An anterior high cervical retropharyngeal approach for C1-C2 intrafacetal fusion and transarticular screw insertion. J Clin Neurosci 2011;18:1705-8.
26. Inose H, Yoshii T, Kimura A, et al. Comparison of clinical and radiographic outcomes of laminoplasty, anterior decompression with fusion, and posterior decompression with fusion for degenerative cervical myelopathy: a prospective multicenter study. Spine (Phila Pa 1976) 2020;45:E1342-8.
27. Coyne TJ, Fehlings MG, Wallace MC, et al. C1-C2 posterior cervical fusion: long-term evaluation of results and efficacy. Neurosurgery 1995;37:688-92; discussion 692-3.
28. Guppy KH, Harris J, Chen J, et al. Reoperation rates for symptomatic nonunions in posterior cervical (subaxial) fusions with and without bone morphogenetic protein in a cohort of 1158 patients. J Neurosurg Spine 2016;24:556-64.
29. Huang RC, Girardi FP, Poynton AR, et al. Treatment of multilevel cervical spondylotic myeloradiculopathy with posterior decompression and fusion with lateral mass plate fixation and local bone graft. J Spinal Disord Tech 2003;16:123-9.
30. Hamilton DK, Smith JS, Reames DL, et al. Safety, efficacy, and dosing of recombinant human bone morphogenetic protein-2 for posterior cervical and cervicothoracic instrumented fusion with a minimum 2-year follow-up. Neurosurgery 2011;69:103-11; discussion 111.
31. Rhee JM, Chapman JR, Norvell DC, et al. Radiological determination of postoperative cervical fusion: a systematic review. Spine (Phila Pa 1976) 2015;40:974-91.