

# Which factor can predict the effect of indirect decompression using oblique lumbar interbody fusion?

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## Abstract

The aim of this study was to investigate the association between various factors of indirect decompression. Previous studies have demonstrated the effectiveness of indirect decompression. There is no consensus regarding the predictive factors for indirect decompression. Facet joint gap (FJG) and bulging disc thickness (BDT) have never been considered as factors in other studies.

We retrospectively reviewed 62 patients who underwent OLIF L4/5 between April 2018 and September 2020. The relationships between cross-sectional area (CSA) change, CSA change ratio, spinal stenosis grade, and various factors were studied. Various factors related to indirect decompression, such as ligament flavum thickness (LFT), foraminal area (FA), disc height (DH), bulging disc thickness (BDT), and facet joint gap (FJG), were measured.

CSA increased from 69.72 mm<sup>2</sup> preoperatively to 115.95 mm<sup>2</sup> postoperatively ( $P < .001$ ). BDT decreased from 4.97 mm preoperatively to 2.56 mm postoperatively ( $P < .001$ ). FJG (Right) increased from 2.99 mm preoperatively to 4.38 mm postoperatively ( $P < .001$ ). FJG (Left) increased from 2.95 mm preoperatively to 4.52 mm postoperatively ( $P < .001$ ). The improvement of spinal stenosis grade was as follows: 1 point up group, 38 patients; 2 point up groups, 19 patients; and 3 point up groups, 3 patients. The correlation factors were prespinal stenosis grade (0.723,  $P < .00$ ), CSA change (0.490,  $P < .00$ ), and FJG change ratio (left, 0.336,  $P < .008$ ).

FJG showed statistical significance with indirect decompression. Indirect decompression principles might be utilized in patients with severe spinal canal stenosis (even grade 4).

**Abbreviations:** ALIF = anterior lumbar interbody fusion, BDT = bulging disc thickness, CSA = cross-sectional area, DH = disc height, FA = foraminal area, FJG = facet joint gap, LFT = ligamentum flavum thickness, MRI = magnetic resonance imaging, ODI = Oswestry Disability Index, OLIF = oblique lumbar interbody fusion, PLIF = posterior lumbar interbody fusion, TLIF = translumbar interbody fusion, VAS = visual analogue scale.

**Keywords:** facet joint, indirect decompression, oblique lumbar interbody fusion, spinal stenosis

## 1. Introduction

Spine surgery is being improved in order to make it minimally invasive. Currently, oblique lumbar interbody fusion (OLIF) is performed at the lumbar L2-S1 level, which is less invasive than open approach posterior lumbar interbody fusion (PLIF), anterior lumbar interbody fusion (ALIF), and translumbar interbody fusion (TLIF). In addition, a study reported that indirect decompression of OLIF was verified in the expansion of the cross-sectional area (CSA) of the spinal canal. Previous studies have demonstrated the effectiveness of indirect decompression using preoperative radiological findings; however, a variation can be observed in the results.<sup>[1-8]</sup> Previous studies have investigated CSA, disc height (DH), ligamentum flavum thickness

(LFT), and foraminal area (FA) association with canal expansion as a factor. There is also no consensus regarding predictive factors that affect radiological outcomes after indirect decompression.<sup>[9]</sup>

Previous studies have reported various factors related to spinal canal expansion, such as LFT, DH, and FA. This study included additional factors that could affect indirect decompression. We analyzed this by adding facet joint gap (FJG) and bulging disc thickness (BDT) as factors that have never been considered before. We selected the operation level as only L4/5, unlike other studies, to reduce the bias. Therefore, this study analyzed the association between various factors and indirect decompression using pre-post radiological outcomes and thereby studied which factors could predict the effect of indirect decompression.

The authors have no funding conflict of interest to disclose.

All data generated or analyzed during this study are included in this published article.

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How to cite this article: Woo J-B, Son D-W, Lee S-H, Lee J-S, Lee SW, Song GS. Which factor can predict the effect of indirect decompression using oblique lumbar interbody fusion? *Medicine* 2022;101:32(e29948).

Received: 10 January 2022 / Received in final form: 8 June 2022 / Accepted: 17 June 2022

<http://dx.doi.org/10.1097/MD.0000000000029948>

## 2. Materials and Methods

### 2.1. Patients

The study protocol was approved by the Institutional Review Board of Pusan National University Yangsan Hospital (IRB No.05-2021-249), and the requirement for informed consent was waived due to the retrospective nature of this study. We retrospectively evaluated 225 consecutive patients who underwent OLIF between April 2018 and September 2020. The exclusion criteria were as follows: (1) trauma, spinal metastatic tumor, and revision of the same level; (2) multilevel fusion; (3) direct decompression; and (4) inability to evaluate the preoperative image because of artifacts. A total of 62 patients were enrolled in the study.

### 2.2. Surgical techniques

All patients underwent OLIF (OLIF25) surgery using the retroperitoneal approach. The surgical procedure was explained in a previous study.<sup>[10]</sup>

### 2.3. Radiological parameters

All radiological assessments were performed by an independent observer who was experienced in spinal diseases. All patients underwent preoperative magnetic resonance imaging (MRI) and postoperative MRI. Most of the postoperative MRIs were followed up 2 weeks after surgery. The MRI was performed with a 3T magnet (Verio, Siemens Healthineers, Republic of Korea) and 4.4 mm for slice thickness.

All radiological parameters were measured on MR T2 weight image, except for DH. The cross-sectional area (CSA) was defined as the disc space or the level with the most severe canal stenosis on the axial cut. CSA was measured along the dura margin (Fig. 1A).

The LFT was measured on both sides of the thickest part of the axial cut (Fig. 1B). The postoperative LFT was measured at the same location. The FA, measured at the upper margin at the L4 pedicle inferior margin, down and posterior margin L5 superior articular process or facet joint margin, anterior site bulging disc thickness (BDT), and vertebral body (Fig. 1C), and disc height (DH) was defined as the distance from the midpoint of the low endplate of the cephalic vertebra to the closest point of the upper endplate of the caudal vertebra on plain X-ray sagittal cut (Fig. 1D).

The bulging disc thickness (BDT) was measured as the distance between the L4 lower endplate posterior and L5 upper endplate posterior margins, drawing a straight line, and the disc bulging apex (Fig. 1E), and the facet joint gap (FJG) was measured in axial cut MR T2 weight images on both sides (Fig. 1F). Spinal stenosis uses Schizas' classification for severity of lumbar spinal stenosis to define grades as 1 to 4.<sup>[11]</sup>

The differences between the preoperative and postoperative images were compared statistically, and the relationship between the change ratio and preoperative factors (CSA, LFT, DH, FA, BDT, and FJG) was analyzed accordingly. The individual factors' (CSA, LFT, DH, FA, BDT, FJG) change was calculated using the following formula: (postoperative factor's—preoperative factor's)(Δ). The factors' (CSA, LFT, DH, FA, BDT, FJG) change ratio was calculated using the following formula: (postoperative factor's—preoperative factor's)/preoperative factor's × 100 (%). Clinical results were compared using the preoperative and postoperative Oswestry Disability Index (ODI),<sup>[12]</sup> visual analog scale (VAS) (Table 1).

### 2.4. Statistical analysis

The change between preoperative and postoperative values in CSA, LFT, FA, DH, BDT, and FJG were analyzed using a

paired t-test. An independent t-test was used to compare radiographic outcomes among subgroups of spinal stenosis (grades 1–4). The independent t-test was also utilized to compare each radiographic parameter between subgroup grade change 1 and grade change 2, 3. Correlations between the CSA change and preoperative CSA, CSA change ratio, preoperative CSA, CSA change, and other radiological parameters were analyzed using Pearson correlation analyses, even when only 1 parameter was normally distributed. Univariate regression analysis was performed using all radiological parameters to investigate the factors that affected the CSA change ratio. Factors associated with borderline significance ( $P < .8$ ) in the univariate regression analysis were also included in the multivariate regression analysis. Statistical significance was set at  $P < .05$ . All analyses were performed using SPSS version 26 for Windows (IBM Co., Armonk, NY).

## 3. Results

### 3.1. Patient characteristics

The average age of the 62 patients was  $65.77 \pm 6.67$  years, and there were more women than men (45/17). The total operative level was 62 segments. 52 patients were diagnosed with spondylolisthesis. Moderate to severe (Grade 3,4) spinal stenosis was diagnosed in 40 patients. The pre VAS was  $5.02 \pm 1.21$ , and the postVAS score improved by  $3.1 \pm 1.43$ . Pre ODI was  $23.32 \pm 7.85$ , and postODI improved to  $19.11 \pm 7.02$ . Bone mineral densitometry was  $-0.777 \pm 1.36$  (Table 1).

### 3.2. Indirect decompression factors of change

The parameters, including CSA of the thecal sac, LFT more severe side, FA more severe side, DH, BDT, and FJG (both), significantly improved after OLIF. Overall, CSA dramatically increased from  $69.72 \pm 37.34 \text{ mm}^2$  to  $115.95 \pm 38.87 \text{ mm}^2$ , average change increased to  $46.23 \pm 20.11 \text{ mm}^2$ , and change ratio to  $88.41 \pm 59.60\%$  ( $P < .001$ ). The LFT decreased from  $5.28 \pm 1.23 \text{ mm}$  to  $3.71 \pm 1.06 \text{ mm}$ , average change decreased from  $-1.57 \pm 1.02 \text{ mm}$ , and change ratio to  $-28.77 \pm 15.78\%$  ( $P < .001$ ). FA increased from  $51.70 \pm 19.59 \text{ mm}^2$  to  $89.11 \pm 32.64 \text{ mm}^2$ , average change  $37.41 \pm 27.85 \text{ mm}^2$ , change ratio  $87.92 \pm 84.48\%$  ( $P < .001$ ). DH increased from  $8.28 \pm 2.34 \text{ mm}$  to  $14.85 \pm 1.91 \text{ mm}$ , average change  $6.56 \pm 1.80 \text{ mm}$ , change ratio  $91.22 \pm 53.79\%$ , ( $P < .001$ ). The BDT decreased from  $4.97 \pm 1.60 \text{ mm}$  to  $2.56 \pm 1.40 \text{ mm}$ , average change decreased from  $-2.41 \pm 1.47 \text{ mm}$ , change ratio  $48.28 \pm 31.74\%$ , ( $P < .001$ ). FJG right increased from  $2.99 \pm 1.18 \text{ mm}$  to  $4.38 \pm 1.66 \text{ mm}$ , average change increased  $1.39 \pm 1.19 \text{ mm}$ , change ratio  $53.85 \pm 51.60\%$ , ( $P < .001$ ). FJG left increased from  $2.95 \pm 1.07$  to  $4.52 \pm 1.74 \text{ mm}$ , average change increased  $1.57 \pm 1.59 \text{ mm}$ , change ratio  $66.98 \pm 83.5\%$ , ( $P < .001$ ) (Table 2).

### 3.3. The relationship of CSA change ratio with various radiological parameter factors

Furthermore, we analyzed the associations with the CSA change ratio. The preCSA correlation coefficient was  $-0.703$ ,  $P < .001$ . The preBDT correlation coefficient was  $-0.256$ ,  $P < .045$ , FJG change(Left) correlation coefficient was  $-0.342$ ,  $P < .006$  (Table 3), and univariate regression analysis demonstrated that the preoperative CSA ( $\beta = 0.70$ ,  $P < .001$ ), and FJG changes (left) ( $\beta = 0.01$ ;  $P = .017$ ) correlated with the CSA change ratio. Multivariate regression analysis demonstrated that preoperative CSA, preFJ (left), preBDT, and FA change were the impact factors that correlated inversely with the CSA change ratio (Table 4).

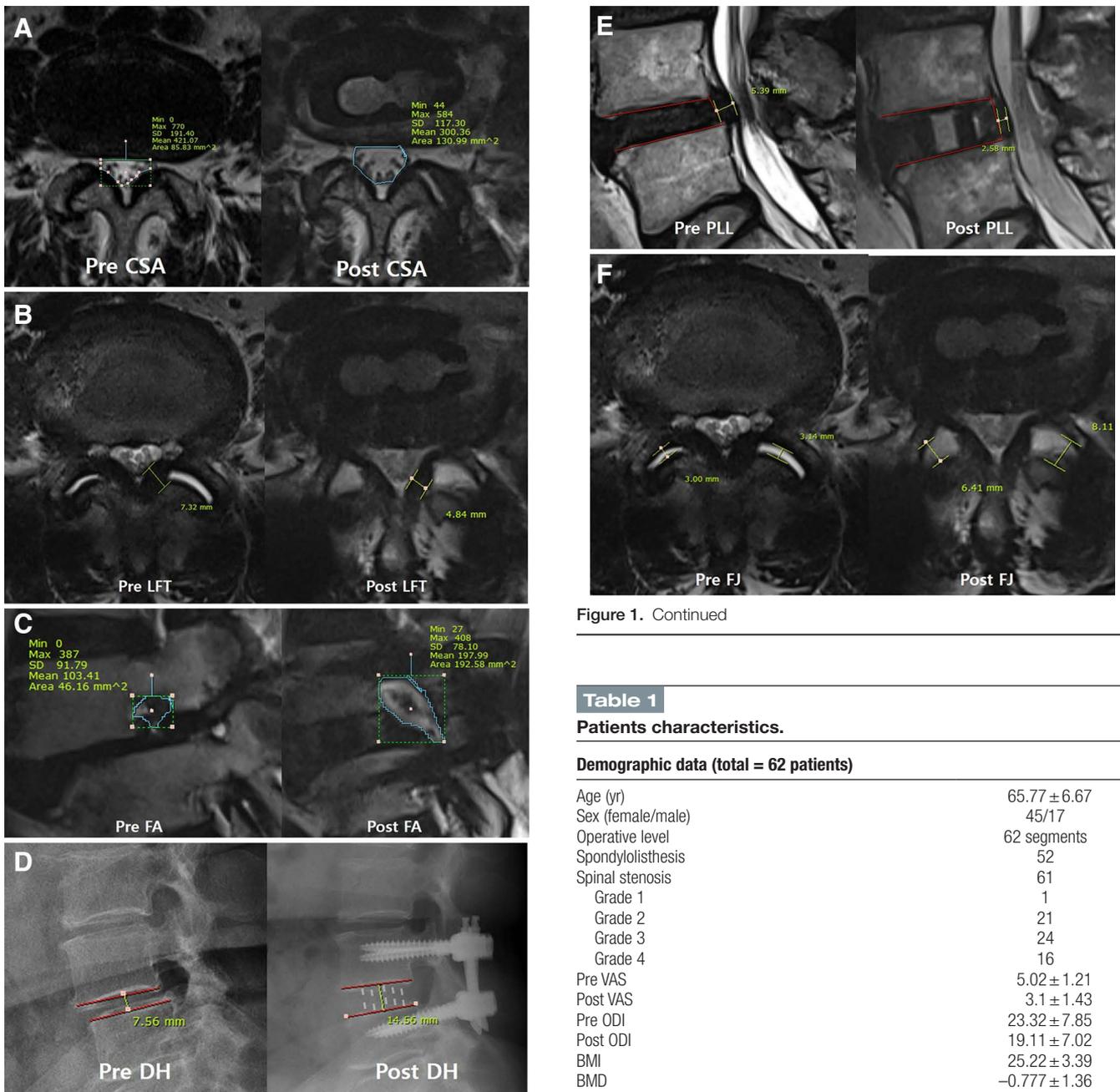


Figure 1. Continued

**Table 1**  
Patients characteristics.

Demographic data (total = 62 patients)	
Age (yr)	65.77 ± 6.67
Sex (female/male)	45/17
Operative level	62 segments
Spondylolisthesis	52
Spinal stenosis	61
Grade 1	1
Grade 2	21
Grade 3	24
Grade 4	16
Pre VAS	5.02 ± 1.21
Post VAS	3.1 ± 1.43
Pre ODI	23.32 ± 7.85
Post ODI	19.11 ± 7.02
BMI	25.22 ± 3.39
BMD	-0.777 ± 1.36

BMD = bone mineral density, BMI = body mass index, ODI = Oswestry disability index, VAS = visual analogue scale.

**Figure 1.** A: The (CSA) was measured along the dura margin, mm<sup>2</sup> on MR T2 weight image. B: LFT was measured on both sides of the thickest part on MR T2 weight image. C: FA was measured upper margin at L4 pedicle inferior margin, down and posterior margin L5 superior articular process or facet joint margin, anterior site PLL and vertebral body. D: DH was defined as the distance from the midpoint of the low endplate of the cephalic vertebra to the closest point of the upper endplate of the caudal vertebra on plain X-ray. E: PLL was measured by the distance between L4 lower endplate posterior and L5 upper endplate posterior margin drawing straight line and the disc bulging apex. F: FJ was measured in axial cut MR T2 weight images on both sides CSA; coronal section area, MR; magnetic resonance, LFT; ligamentum flavum thickness, FA; foraminal area, PLL; posterior longitudinal ligament, DH; disc height, FJ; facet joint.

**3.4. The relationship between spinal stenosis and radiological parameter factors**

Spinal stenosis was preoperative grade 1, 1; grade 2, 21; grade 3, 24; and grade 4, 16 patients; respectively. Postoperative spinal stenosis grade was grade 1, 29; grade 2, 31; grade 3, 2;

and grade 4, 0 or no patient; respectively. The spinal stenosis change ratio was 1.32 ± 0.62. (Table 5). We classified the patients into grade change 1 group (n = 38) and grade change 2,3 (n = 21) accordingly. Preoperative CSA was grade change 1; 50.74 ± 22.23 mm<sup>2</sup>, grade change 2, 3; 56.29 ± 26.34 mm<sup>2</sup>. CSA change was grade change 1; 40.58 ± 18.50 mm<sup>2</sup>, grade change 2; 3 55.23 ± 17.90 mm<sup>2</sup> (P < .015) LFT change was grade change 1; -1.27 ± 0.91 mm, grade change 2,3; -1.78 ± 0.99 mm (P < .10). FJG (Left) was grade change 1; 2.06 ± 1.21 mm, grade change 2,3; 2.32 ± 1.75 mm (P < .224) (Table 6). In addition, we evaluated the relationship between radiological parameters and changes in spinal stenosis grade. preoperative spinal stenosis grade (0.723, P < .001), CSA change (0.490, P < .001), and FJG change ratio(left) (0.336, P < .008) (Table 7).

**Table 2**  
**Radiographic outcome.**

	Preoperative	Postoperative	Change	Change ratio(%)	P value
CSA (mm <sup>2</sup> )	69.72 ± 37.34	115.95 ± 38.87	46.23 ± 20.11	88.41 ± 59.60	.001
LFT (mm)	5.28 ± 1.23	3.71 ± 1.06	-1.57 ± 1.02	-28.77 ± 15.78	.001
FA (mm <sup>2</sup> )	51.70 ± 19.59	89.11 ± 32.64	37.41 ± 27.85	87.92 ± 84.48	.001
DH (mm)	8.28 ± 2.34	14.85 ± 1.91	6.56 ± 1.80	91.22 ± 53.79	.001
BDT (mm)	4.97 ± 1.60	2.56 ± 1.40	2.41 ± 1.47	48.28 ± 31.74	.001
FJG (Rt) (mm)	2.99 ± 1.18	4.38 ± 1.66	1.39 ± 1.19	53.85 ± 51.60	.001
FJG (Lt) (mm)	2.95 ± 1.07	4.52 ± 1.74	1.57 ± 1.59	66.98 ± 83.5.	.001

% change indicates mean value of variables that change from preoperative to postoperative in percent, mm, millimeter, mm<sup>2</sup>, square millimeters.

CSA, coronal section area, BDT = bulging disc thickness, DH = disc height, FA = foraminal area, FJG = facet joint gap, LFT = ligamentum flavum thickness, Lt = left, Rt = right.

**Table 3**  
**Correlation of CSA change ratio various radiological parameters.**

	Correlation Coefficient	P value
Pre CSA	-.703	.001
BDT change	-.048	.816
FJG change (Lt)	-.342	.006

BDT = bulging disc thickness, CSA = coronal section area, FJG = facet joint gap.

#### 4. Discussion

Oblique lateral interbody fusion (OLIF) has been performed for spinal stenosis, spondylolisthesis, and degenerative lumbar diseases. OLIF uses a potential retroperitoneal space, and a spine surgeon can access the spinal structure (intervertebral disc, vertebral body) relatively easily with minimal bleeding and muscle injury.<sup>[13]</sup> Additionally, there is less chance of injury to the lumbar plexus on account of usage of the prepoas approach. Owing to these advantages, OLIF can operate in beginners without difficulty.<sup>[10]</sup> However, various complications can occur in the OLIF, such as ureter injury, vessel injury, psoas paresis, respectively.<sup>[10]</sup>

Direct decompression approaches such as anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF) have already proven to be effective.<sup>[14-16]</sup> However, there are also reports of iatrogenic applications due to surgery.<sup>[17]</sup> On the other hand, OLIF, one of the indirect decompression operations, has relatively low incidence of intraoperative iatrogenic complications, such as muscle, nerve root injury, and thecal sac injury.

Implantation of the interbody cage affects indirect decompression by decreasing the bulging disc and ligamentum axis through disc height restoration.<sup>[18,19]</sup> Therefore, there are many research papers available on study of radiologic parameters and their effects on indirect decompression which have focused on the CSA, disc height, and formal areas. Sato et al reported that CSA increased by 19%, disc height by 61%, and formal area by 21% in 20 cases.<sup>[7]</sup> Fujibayashi et al in 28 cases reported that CSA increased by 30.2% and disc height by 82%, and, preoperative CSA was associated in the correlation test.<sup>[11]</sup> Limthongkul et al in 35 cases especially focussed on ligamentum flavum thickness (LFT). In this study, CSA increased by 50.8%, right LFT decreased by -17.0%, and left LFT decreased by -17.6%, and these changes were not related to facet degeneration.<sup>[2]</sup> Park et al in 41 cases reported that CSA increased by 36.5% after OLIF.<sup>[6]</sup> The Numeric paper CSA reported an increase, however, there was a variation in the degree of increase. This study showed that the CSA increased by approximately 88.41% after indirect decompression through OLIF in 62 patients. The CSA increase in our study shows similar results as in previous studies, and the CSA change ratio has been larger than that reported in other studies. In many cases, this study is more specific than any other research conducted so far, and there are many cases of moderate to severe spinal stenosis; so these results are derived accordingly.

This study conducted an association study of the various factors related to changes in CSA. First, preoperative CSA was classified as a factor associated with CSA change, as in Fujibayashi's study.<sup>[11]</sup> Shimizu et al compared the clinical symptom improvement rate for the good versus poor group; the good group had a low preoperative CSA and had more change in the CSA.<sup>[8]</sup> It is possible to predict the effect of indirect decompression in severe spinal stenosis (Table 3). We had an indirect decompression of a

**Table 4**  
**Result of regression analysis for CSA change ratio.**

	univariate				Multivariate			
	β	SE	Standardized β	P value	β	SE	Standardized β	P value
Pre CSA	-1.123	0.146	-0.703	.001	-0.883	0.099	-0.553	.001
Pre BDT	-1.789	4.797	-0.048	.710	7.787	2.563	0.209	.004
Pre FJG (Lt)	-4.880	7.139	-0.088	.497	-7.864	3.446	-0.142	.026
FA change	-0.238	0.276	-0.111	.390	-0.292	0.141	-0.136	.044
Pre LFT	6.032	6.196	0.125	.334				
Pre FA	-0.307	0.391	-0.101	.435				
Pre DH	0.097	3.285	0.004	.976				
Pre FJG (Rt)	-0.138	6.526	-0.003	.963				
LTF change	-8.051	7.484	-0.138	.286				
DH change	2.316	4.260	0.070	.589				
BDT change	-1.219	5.226	-0.030	.816				
FJG (Rt) change	10.298	6.301	0.206	.107				
FJG (Lt) change	11.277	4.610	0.301	.017				

BDT = bulging disc thickness, CSA = coronal section area, DH = disc height, FA = foraminal area, FJG = facet joint gap, LFT = ligamentum flavum thickness.

**Table 5**  
**Spinal stenosis outcome.**

	Preoperative	Postoperative	Change ratio(%)
Grade 1	1	29	1.32 ± 0.62
Grade 2	21	31	
Grade 3	24	2	
Grade 4	16	0	

**Table 6**  
**Compare to Spinal stenosis grade change 1 and 2,3 radiological outcome.**

	Grade change1 (n = 38)	Grade change 2,3 (n = 21)	P value
Pre CSA	50.74 ± 22.23	56.29 ± 26.34	.475
CSA change	40.58 ± 18.50	55.23 ± 17.90	.015
LFT change	-1.27 ± 0.91	-1.78 ± 0.99	.10
FA change	36.07 ± 23.9	40.33 ± 30.39	.629
DH change	6.61 ± 1.70	6.42 ± 1.52	.722
BDT change	2.51 ± 1.20	2.23 ± 1.96	.600
FJG (Rt)	1.76 ± 1.20	1.67 ± 1.12	.818
FJG (Lt)	2.06 ± 1.21	2.32 ± 1.75	.224

BDT = bulging disc thickness, CSA = coronal section area, DH = disc height, FA = foraminal area, FJG = facet joint gap, LFT = ligamentum flavum thickness.

**Table 7**  
**The relationship between spinal stenosis change and radiological parameters.**

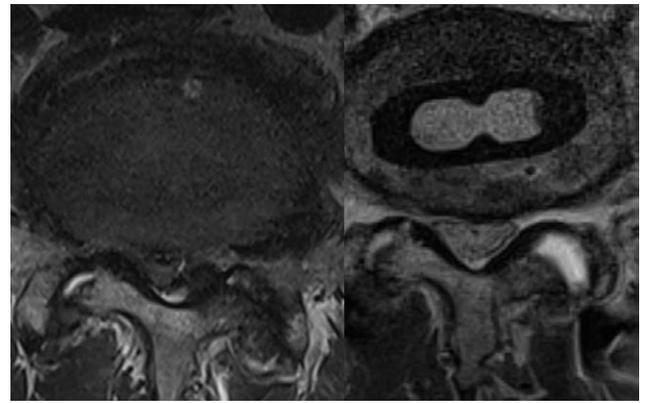
		P value
Pre grade	0.723	0.001
CSA change	0.490	0.001
FJG (Lt) change ratio	0.336	0.008

BDT = bulging disc thickness, CSA = coronal section area, FJG = facet joint gap.

patient with spinal stenosis grade 4, the radiologic outcome was grade 2, and the clinical outcome had improved in this patient (Fig. 2).

DH showed an increase in indirect decompression in previous studies.<sup>[1,3,4,7,8]</sup> In this study, DH showed an increase of 91%. Through a lot of research, it is proven that theoretically, DH's restoration causes structural changes in the surrounding structure, resulting in indirect decompression. However, in previous studies, the association between CSA and DH was statistically meaningless, same as this study result. We assumed that indirect decompression had multifactorial characteristics, so there would be complexity in analyzing each other's associations. We mostly use a 12 mm height cage (70%) in OLIF. If we use the highest cage for maximum disc height elevation, a vertebral body endplate fracture may occur. Thus, although statistically meaningless, based on radiological output and theoretical parts, DH changes can be thought of as a predictive factor for spinal canal expansion. Therefore, DH change that can be checked during surgery is considered an intraoperative predictive factor for indirect decompression.

Additionally, we measured the bulging disc thickness as a factor associated with the DH change. BDT determines the degree of ventral site decompression in the CSA. This study shows that the BDT decreases by 48.28%. The correlation test showed 0.256,  $P < .045$ , and there was an association in multivariate regression analyses ( $P < .004$ ). BDT is one of the factors correlated with the CSA change ratio. We assumed that the change in BDT was related to DH change. DH change preceded, followed by posterior longitudinal ligament stretching and bulging



**Figure 2.** Left image was diagnosed with spinal stenosis grade 4 due to disc bulging and LFT. Right image was improved to disc bulging, LFT, CSA, FJ space expansion after interbody cage via OLIF.

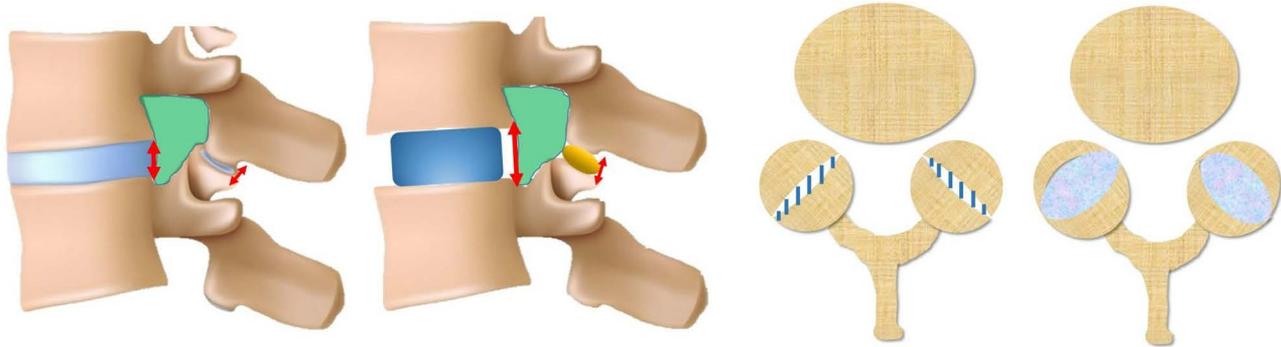
disc restoration. This change resulted in a decompression effect to the ventral portion of the spinal canal.

As the indirect decompression becomes thinner, the ligamentum flavum posterior spinal column structure affects the expansion of the spinal canal. The first study on ligamentum flavum thickness (LFT) was done by Limthongkul, which resulted in a reduction in LF to -17.0%.<sup>[2]</sup> In this study, LFT decreased by 28.77% as well. However, Limthongkul's research did not secure a statistical association with CSA.

Both DH and LFT showed significant changes; however, since there was no statistical significance noted, we considered other related factors. This study analyzed facet joint (FJ) expansion, which was not done in any other study. Facet joints can also affect postspinal structures, foraminal area, and ligamentum flavum through widening and expansion, and this can be identified in real time with intraoperative images such as DH. Previous studies have shown that facet joint degeneration does not interfere with indirect decompression.<sup>[2,5]</sup> This study showed that the right facet joint increased by 53.85% and the left facet joint increased by 66.98%. In addition, the facet joints were.342 and had  $P < .006$  in the correction test, which was more relevant than other factors except for preoperative CSA. These results are considered to affect spinal canal expansion in conjunction with foraminal area expansion and a decrease in ligamentum flavum thickness. Facet joint space expansion occurs in various directions. When the gap between the vertebral bodies is widened by the interbody cage, the facet point also causes expansion in the vertical, horizontal, and diagonal directions (Fig. 3). Therefore, if facet joint expansion is identified as an intraoperative image, it is a good predictor of the effectiveness of indirect decompression during surgery.

Spinal stenosis was analyzed in the group that improved by more than 2 grades and the group that improved by 1 grade through indirect decompression. As a result, the preoperative spinal stenosis grade, CSA change, and FJ change ratio were identified as influential factors. Structurally, the interbody cage has an implantation anterior spinal column and a posterior spinal column that is affected by ligamentum flavum thickness and facet joint extension. Indirect decompression can also be attempted in patients with severe spinal stenosis because of the various factors that affect indirect decompression. Facet joint extension and DH change are easy to identify with intraoperative imaging; so it will be a good factor in predicting the indirect decompression effect during surgery.

Complications during OLIF indirect decompression surgery were reported in a previous study. The major complications related to cage insertion were cage subsidence occurring 8 case, cage malposition 2case and vertebral body fracture 2case occurring.<sup>[10]</sup>



**Figure 3.** Facet joint space expansion to multiple direction. Sagittal view: illustration showing the vertical expansion of facet joint space. Axial view: illustration showing the axial expansion of facet joint space.

This study has several limitations. First, this study was retrospective in nature. Second, the first study focused on only the early effects of indirect decompression on facet joint expansion (BDT). Third, more research is needed on the statistical correlation factors.

## 5. Conclusion

All factors significantly changed after OLIF. DH was the only factor that the operator could control during surgery, but in the result, it did not emerge as an independent factor. However, the FJG showed statistical significance with indirect decompression. Indirect decompression principles might be utilized in patients with severe spinal canal stenosis (even grade 4). Further research is needed on the relationship between DH, FJG changes, and spinal canal expansion.

## Author contributions

Joon Bum Woo : data curation, Formal analysis, Roles/Writing - original draft, Visualization  
 Dong Wuk Son : Conceptualization, Methodology, Writing - review & editing, Project administration  
 Su Hun Lee : Data curation, Formal analysis, Roles/Writing - original draft,  
 Jun Seok Lee : Formal analysis, Roles/Writing - original draft,  
 Sang Weon Lee : Writing - review & editing  
 Geun Sung Song : Conceptualization, Writing - review & editing.

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