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Research article

# Evaluating the efficacy and suggesting technical optimizations for endoscopic lumbar interbody fusion across different lumbar spondylolisthesis types

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ABSTRACT

*Purpose:* To evaluate the efficacy of the endoscopic lumbar interbody fusion technique across different types of lumbar spondylolisthesis, specifically Grade I and Grade II, and suggest technical optimizations based on therapeutic outcomes, complications, and patient satisfaction for both grades.

*Methods:* We analyzed data from 57 L4 to 5 spondylolisthesis patients, all categorized as either Grade I or Grade II, comprising 31 males and 26 females. Of these, 36 were diagnosed with Grade I and 21 with Grade II. All subjects underwent the endoscopic lumbar interbody fusion procedure. Primary evaluation metrics included pre and post-operative Vasual Analogue Scale ( VAS ) pain scores, Osewewtry Disability Index ( ODI ) functional scores, surgical duration, intraoperative blood loss, degree of spondylolisthesis correction, complications, and patient satisfaction levels.

*Results:* At a minimum of 6 months post-operation, the VAS score for the Grade I cohort reduced from an initial $7.30 \pm 0.69$ to $2.97 \pm 0.47$, while the Grade II cohort saw a decrease from $7.53 \pm 0.56$ to $3.37 \pm 0.62$ ($P = 0.0194$). The ODI score in the Grade I group declined from $66.88 \pm 5.15$ % pre-operation to $29.88 \pm 6.36$ % post-operation, and in the Grade II group, it decreased from $69.33 \pm 5.27$ % to $34.66 \pm 6.01$ % ($P = 0.0092$). The average surgical duration for the Grade I group stood at $155.72 \pm 17.75$ min, compared to $180.38 \pm 14.72$ min for the Grade II group ($P < 0.001$). The mean intraoperative blood loss for the Grade I group was $144.58 \pm 28.61$ ml, whereas the Grade II group registered $188.23 \pm 9.41$ ml ($P < 0.001$). Post-surgery, 83 % of the Grade I patients achieved a correction degree exceeding 80 %, and 61 % of the Grade II patients surpassed 50 % ($P = 0.0055$). Complication rates were recorded at 8 % for Grade I and 16 % for Grade II. Patient satisfaction reached 94 % in the Grade I cohort and 90 % in the Grade II cohort.

*Conclusion:* Endoscopic lumbar interbody fusion showcases promising therapeutic outcomes for both Grade I and Grade II lumbar spondylolisthesis. However, surgeries for Grade II spondylolisthesis tend to be lengthier, more challenging, involve greater blood loss, and have a heightened complication risk. Tailored technical adjustments and enhancements are essential for addressing the distinct spondylolisthesis types.

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Abbreviation List

| Abbreviation | Full name |
|---|---|
| ODI | Osewewtry Disability Index |
| VAS | Vasual Analogue Scale |
| MRI | Magnetic Resonance Imaging Computed Tomograph |
| *Endo*-LIF | Endoscopic Lumbar Interbody Fusion |

## 1. Introduction

Lumbar spondylolisthesis is a prevalent spinal condition. Grade I and Grade II spondylolisthesis are its most common classifications [1]. The treatment approach is contingent upon the type and severity of the slippage. The minimally invasive nature of the endoscopic lumbar interbody fusion technique has garnered significant attention in recent years [2,3]. Lumbar spondylolisthesis, a common spinal ailment, has witnessed an escalating global incidence in recent years [4]. This disorder profoundly affects patients, impinging on their daily activities and overall well-being [5]. Although traditional open surgical interventions have established their efficacy, their adoption in clinical settings has been curtailed due to the associated significant trauma, prolonged recovery durations, and potential complications [6]).

Amidst the swift evolution of contemporary medical technology, minimally invasive procedures have carved a niche in the realm of spinal disorder treatments [7,8]. Spinal endoscopy, especially, has garnered acclaim from both medical professionals and patients, attributed to its reduced surgical invasiveness, expedited recovery timelines, and diminished complication risks [9]. Nonetheless, while the promise of endoscopic lumbar interbody fusion (*Endo*-LIF) in addressing lumbar spondylolisthesis is evident, the technique's efficacy across diverse spondylolisthesis gradings and its optimal application methodologies remain under active discussion [10,11].

In pursuit of a comprehensive understanding of *Endo*-LIF's role in lumbar spondylolisthesis management, this study endeavors to meticulously assess its therapeutic outcomes across varied spondylolisthesis categories. Additionally, we aim to proffer technical optimization recommendations, aspiring to delineate a more informed and pragmatic therapeutic approach for clinical adoption.

## 2. Materials and methods

### 2.1. Inclusion and exclusion and general information

#### 2.1.1. Study population

This research represents a retrospective cohort analysis spanning from January 2021 to December 2022. The primary objective is to assess the therapeutic outcomes of endoscopic lumbar interbody fusion (*Endo*-LIF) across varying classifications of lumbar spondylolisthesis and to delve into potential technical refinements and optimization strategies. We meticulously curated patients from our hospital's electronic medical record system who underwent *Endo*-LIF within the designated period, ensuring data integrity and precision. We collated data from a total of 57 patients diagnosed with L4-5 spondylolisthesis, subsequently categorizing them based on the severity of slippage into: Grade I spondylolisthesis (36 patients) and Grade II spondylolisthesis (21 patients). An exhaustive review of each patient's medical history was undertaken, capturing all relevant data aligned with the study's objectives. All participants had a guaranteed follow-up of at least six months to gauge the enduring efficacy and potential complications of the procedure. Notably, a singular senior surgeon executed all surgical interventions.

From the cohort of 57 L4-5 spondylolisthesis patients, 31 were male, and 26 were female. All hailed from our institution and underwent *Endo*-LIF between January 2021 and December 2022. Based on the slippage severity, they were bifurcated into two primary categories: Grade I spondylolisthesis encompassing 36 patients and Grade II spondylolisthesis with 21 patients.

#### 2.1.2. Inclusion criteria

(1) Individuals who underwent *Endo*-LIF at our facility.(2) Recurrent lumbar discomfort, potentially accompanied by intermittent claudication.(3) Radiological confirmation of single-segment Meyerding Grade I or II spondylolisthesis (L4/L5).(4) Those who didn't exhibit significant alleviation post 3–6 months of conventional conservative treatments and had a definitive diagnosis.(5) Availability of comprehensive pre and post-operative follow-up records.

#### 2.1.3. Exclusion criteria

(1) Prior history of lumbar surgical interventions.(2) Presence of spinal infections or tumors.(3) Manifestation of lateral scoliosis. (4) Multiple underlying health conditions rendering them unsuitable for surgery.(5) Diagnosis of cauda equina syndrome.

### 2.2. Surgical Technique:Endoscopic lumbar interbody fusion

(1) The patient undergoes general anesthesia and is carefully positioned prone. Adequate support is ensured for the head, chest, and pelvis to minimize any intraoperative movement.(2) Utilizing a *C*-arm for precise positioning, the L4/5 intervertebral space and posterior midline are delineated and marked. Standard disinfection procedures are applied to the lumbar dorsal area, followed by draping.(3) A strategic skin puncture is executed 1.5 cm lateral to the lumbar posterior midline, aligned with the L4/5 space. The puncture is directed towards the L4/5 facet joint from the symptomatic side. Under fluoroscopic visualization, a guide rod is adeptly

inserted into the L4/5 facet joint space region. Upon confirming optimal positioning, dilators and a working sheath are sequentially introduced. Endoscopic guidance facilitates the removal of portions of the L4 inferior and L5 superior articular processes, thereby expanding the lamina and reshaping the spinal canal.(4) Any thickened yellow ligaments are meticulously excised using specialized rongeurs. Concurrently, any protruding points of the annulus fibrosus are leveled. A significant portion of the protruding intervertebral disc is extracted, ensuring thorough decompression of the L5 nerve root. The annular tear is then treated with a radiofrequency probe. Post-decompression, the dural sac is visibly bulging with a healthy pulsation.(5) The L4/5 intervertebral disc is addressed under the bone graft channel. After disc removal, a combination of autologous and select allogeneic bone granules are implanted. Tailored endoscopic interbody fusion devices, laden with autologous bone granules, are positioned between the L4/5 vertebrae. The optimal placement of the fusion device is ascertained via fluoroscopy.(6) Guided by fluoroscopy, bilateral punctures target the pedicle roots of L4 and L5. Four screws are strategically placed, succeeded by the affixation of titanium rods. Once the rods are securely connected, fluoroscopy is employed to validate the precise positioning and appropriate length of the internal fixation devices.(7) Concluding the procedure, the working sheath and endoscope are carefully withdrawn, and the surgical site is seamlessly sutured intradermally口.

### 2.3. Outcome measures

The metrics used in this study encompass: the VAS pain score to gauge patients' pain intensity, the ODI functional score to quantify functional limitations in individuals with lumbar discomfort, duration of the surgery, volume of intraoperative blood loss, percentage representation of postoperative spondylolisthesis realignment, documentation of post-surgical complications, and patient satisfaction ascertained through a five-point evaluation scale.

### 2.4. Statistical analysis

In our study, statistical analyses were conducted using SPSS 26.0 software. For continuous variables, such as VAS pain scores, ODI functional scores, duration of surgery, and intraoperative blood loss, we applied the independent samples *t*-test to draw comparisons between the Grade I and Grade II spondylolisthesis groups. For categorical data, including complication rates and patient satisfaction levels, the chi-square test was utilized. Furthermore, we delved into the associations between postoperative spondylolisthesis realignment and other evaluative metrics using Spearman's correlation analysis.

## 3. Results

### 3.1. General data

All surgeries were performed at the L4/L5 segment. The study encompassed 57 patients with lumbar spondylolisthesis, of which 31 were males and 26 females. The average age stood at 47.80 ± 8.24 years, with a mean weight of 66.56 ± 12.17 kg, an average height of 166.90 ± 9.76 cm, and a BMI averaging 25.05 ± 3.34 kg/m^2. In terms of spondylolisthesis grading, 36 patients fell under Grade I and 21 were categorized as Grade II (seeTable 1).

### 3.2. Clinical efficacy assessment

Surgical Duration and Blood Loss: The Grade I group had an average surgical duration of 155.72 ± 17.75 min and an average blood loss of 144.58 ± 28.61 ml. For the Grade II group, these figures were 180.38 ± 14.72 min and 188.23 ± 9.41 ml respectively. Both surgical duration and blood loss had p-values of <0.001. The Grade I group's preoperative ODI scores were 66.88 ± 5.15 %, which reduced to 29.88 ± 6.36 % post-surgery and further to 26.63 ± 5.13 % at the 6-month follow-up. Their VAS scores decreased from a preoperative 7.30 ± 0.69 to 2.97 ± 0.47 post-surgery, settling at 2.75 ± 0.53 six months later. For the Grade II group, the initial ODI scores of 69.33 ± 5.27 % dropped to 34.66 ± 6.01 % post-surgery and remained at 34.66 ± 5.52 % after six months. VAS scores

**Table 1**
Basic patient data.

| | Grade I spondylolisthesis | Grade II spondylolisthesis | P |
|---|---|---|---|
| Gender | | | |
| Male | 19 | 12 | 0.9653 |
| Female | 17 | 9 | 0.9653 |
| Age ( y ) | 47.42 ± 7.74 | 48.48 ± 9.19 | 0.6438 |
| Height ( m ) | 166.08 ± 9.16 | 168.19 ± 10.81 | 0.4367 |
| Weight ( kg ) | 65.83 ± 12.04 | 67.81 ± 12.60 | 0.5591 |
| BMI ( $kg/m^2$ ) | 24.72 ± 3.33 | 25.61 ± 3.38 | 0.3386 |
| Smoke | | | |
| Yes | 16 | 11 | |
| No | 20 | 10 | |
| Surgery time ( min ) | 155.72 ± 17.76 | 180.38 ± 14.75 | 0.0000 |
| Blood loss ( ml ) | 144.58 ± 28.61 | 188.24 ± 9.42 | 0.0000 |

Note: Data is presented as mean ± standard deviation.

transitioned from 7.53 ± 0.56 pre-surgery to 3.37 ± 0.62 post-surgery, and 3.30 ± 0.60 at the six-month mark. The p-values for ODI and VAS scores were 0.0092 and 0.0194, respectively. Neurological Function: Post-surgery, the Grade I group witnessed substantial neurological improvements, with 6 patients advancing from Frankel grade D to E and 7 from C to D. In the Grade II group, 3 patients progressed from D to E and another 3 from C to D.

(Figs. 1-3).

### 3.3. Radiological findings

Postoperative Spondylolisthesis Realignment: According to DR examinations, post-surgery, 83 % of the Grade I group achieved a realignment of 80 % or more, while in the Grade II group, 61 % achieved a realignment of at least 50 %(P = 0.005). (Fig. 4).

### 3.4. Complications

In the Grade I group, 3 out of the total (8 %) encountered complications: one case of incisional infection that was successfully treated with antibiotics; one postoperative hematoma that was managed conservatively until it was absorbed; and one patient who reported increased postoperative lumbar pain, which was alleviated with medication and physical therapy. In the Grade II group, 4 out of the total (16 %) had complications: one had nerve root injury with subsequent symptom relief post-treatment; one experienced a dural tear with cerebrospinal fluid leakage that was conservatively managed; and two reported persistent postoperative back pain, which was mitigated with medication and physical therapy.

## 4. Discussion

This study was designed to assess the therapeutic outcomes of different grades of lumbar spondylolisthesis when treated with endoscopic spinal fusion techniques and to offer suggestions for technical refinement. Our findings reveal that both Grade I and Grade II lumbar spondylolisthesis patients experienced positive outcomes post endoscopic spinal fusion. However, the Grade II cohort encountered challenges due to obscured anatomical structures during the endoscopic procedure. This not only added complexity to the surgery but also heightened the potential for complications [12].

With the evolution of minimally invasive spinal techniques in recent years, endoscopic spinal procedures have been recognized as a potent treatment modality for lumbar spondylolisthesis [13]. Contemporary research also underscores that endoscopic surgeries, when juxtaposed with traditional open surgeries, result in minimized incisional trauma, expedited recovery, and a diminished complication rate [14]. Furthermore, advancements in biomaterials and 3D printing technologies [15,16] have paved the way for tailored bone grafts and fixation devices, broadening the horizons for endoscopic fusion techniques [17].

In alignment with the prevailing literature, our results corroborate the efficacy of endoscopic spinal fusion in addressing lumbar spondylolisthesis [18]. For patients with Grade II spondylolisthesis, we advocate for bilateral facet joint decompression based on our experience. This approach facilitates a more effective nerve root release and offers an expanded surgical workspace, thereby optimizing the success rate and curtailing complications. While bilateral decompression might extend surgical duration and elevate blood loss, the majority of patients manifest superior realignment compared to unilateral decompression.

It's also pertinent to highlight that while our study predominantly centered on Grade I and II lumbar spondylolisthesis, the therapeutic strategy for Grade III spondylolisthesis has also captured our interest. Grade III denotes a pronounced anterior displacement of the lumbar vertebrae, resulting in significant anatomical alterations [19]. Such pronounced displacement can lead to intensified nerve compression, stability challenges, and associated clinical manifestations. Consequently, addressing Grade III spondylolisthesis might demand intricate and robust fixation methodologies.

The deployment of endoscopic fusion techniques for Grade III spondylolisthesis remains somewhat circumscribed, primarily due to the escalated technical challenges, augmented stability requirements, and increased complication risks. Yet, as technology forges

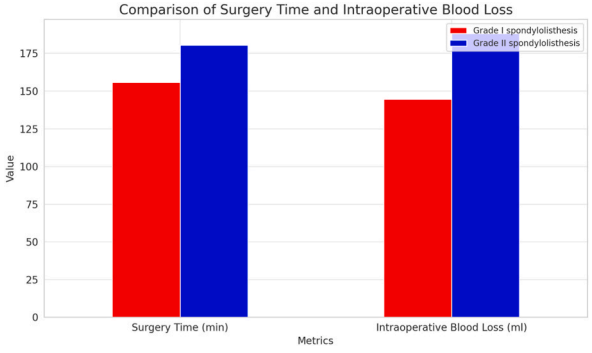


**Fig. 1.** This graph compares the average surgical duration and intraoperative blood loss between patients with Grade I and Grade II spondylolisthesis. It is evident from the chart that the Grade II group had a longer surgery time and greater blood loss.

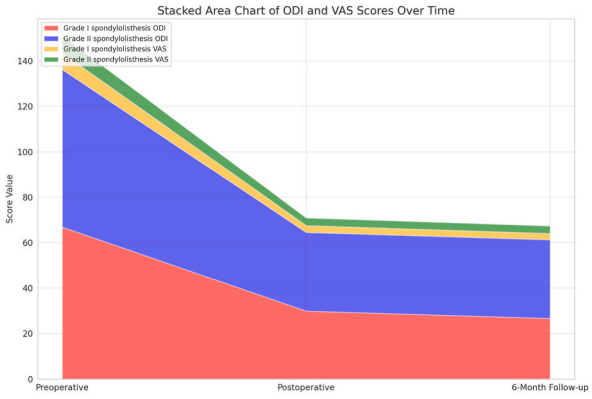


**Fig. 2.** This graph illustrates the evolution of ODI and VAS scores for both Grade I and Grade II spondylolisthesis patients at pre-operative, post-operative, and 6-month follow-up intervals. As depicted, the Grade I group consistently registered lower ODI and VAS scores across all time points compared to the Grade II group. Notably, both groups experienced a marked decrease in ODI and VAS scores following surgery. By the 6-month follow-up, the scores for both cohorts stabilized, mirroring their post-operative values. This underscores the surgery's efficacy in significantly enhancing the patients' ODI and VAS scores, with these improvements enduring at least half a year post-operation.

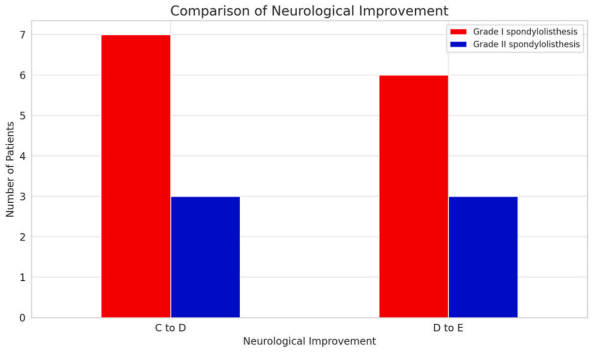


**Fig. 3.** This chart illustrates the comparison of neural function improvement between the two groups. It depicts the number of patients whose post-operative neural function advanced from a Frankel grade of C to D and from D to E.

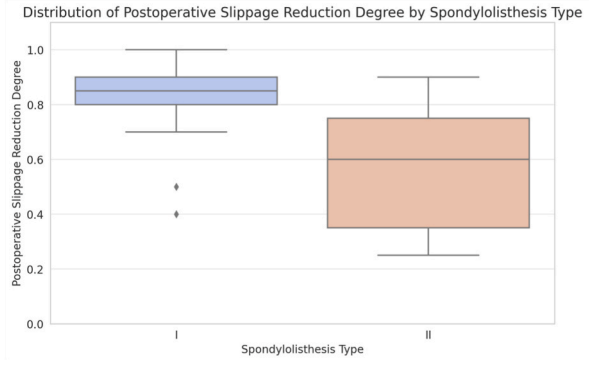


**Fig. 4.** This graph illustrates the post-operative reduction levels of spondylolisthesis for patients categorized under Grade I and II. From the box plot, the central line within each box signifies the median. The top and bottom edges of the box delineate the third (Q3) and first quartiles (Q1), respectively. Points situated outside the box are potential outliers. The "whiskers" extending from the box depict the data's spread, excluding these outliers. Notably, the graph reveals that patients with Grade I spondylolisthesis generally achieve a more pronounced post-operative reduction compared to their Grade II counterparts.

ahead, a subset of seasoned spinal surgeons might venture to treat select Grade III cases using endoscopic modalities. Such endeavors typically mandate a bespoke assessment, weighing the patient's unique conditions, anatomical nuances, and surgical risks.

Overall, for Grade III spondylolisthesis, conventional open surgery may still hold its ground as the method of choice [20]. However,

as technological frontiers expand, we anticipate a gradual uptick in the adoption of endoscopic techniques for this condition. This evolution underscores the potential for the expanding applicability of endoscopic spinal techniques, emphasizing that surgical decisions should always be anchored in comprehensive clinical evaluations and in-depth patient consultations.

As the landscape of surgical tools and methodologies continues to evolve, consistent surgical training and acclimatization to novel tools become imperative for optimizing surgical outcomes. These cutting-edge techniques and instruments might proffer enhanced surgical visualization and precision, thereby bolstering the surgery's success quotient [21]. We underscore the importance of routinely collating and analyzing surgical outcomes to perpetually refine techniques and elevate therapeutic efficacy.

In our study, we noted instances of postoperative pain in both Grade I and Grade II patient groups, underscoring the need to understand the underlying causes and enhance pain management strategies. In the Grade I group, one patient experienced increased lumbar pain post-surgery, likely due to inflammatory responses or minor nerve irritation from the surgical process. This discomfort was effectively managed with medication and physical therapy, demonstrating that appropriate postoperative care can successfully address such issues. In the Grade II group, two patients reported persistent back pain following more extensive surgical interventions, potentially exacerbated by pre-existing conditions. The effective use of medications and physical therapy mitigated this pain, illustrating that even challenging symptoms are manageable with established pain management protocols. These cases highlight the importance of integrating effective pain management into postoperative care plans, with regular follow-ups and a multidisciplinary approach crucial for the early identification and treatment of post-surgical pain. Additionally, thorough preoperative assessments are essential to identify potential risks and tailor interventions that may reduce the likelihood of severe pain after surgery.

Lastly, it's worth noting the inherent limitations of our study, including its modest sample size and retrospective nature. Prospective, randomized controlled trials in future endeavors would further substantiate our findings and recommendations.

## 5. Conclusion

This study provides a comprehensive assessment of the therapeutic efficacy of endoscopic spinal fusion techniques across different grades of lumbar spondylolisthesis. Our results underscore that both Grade I and Grade II spondylolisthesis benefit significantly from endoscopic spinal fusion. Notably, patients with Grade I spondylolisthesis experienced swift recovery and expressed high satisfaction levels. In contrast, Grade II spondylolisthesis presents increased surgical challenges due to obscured anatomical landmarks, potentially leading to a higher risk of complications. Drawing from our research insights and surgical expertise, we advocate for bilateral facet joint decompression in Grade II cases to enhance vertebral realignment and reduce associated risks. As technological advancements continue and novel surgical tools emerge, the potential for leveraging endoscopic spinal fusion in treating lumbar spondylolisthesis becomes even more promising. Future endeavors should delve deeper into refining and adapting these techniques to offer even safer and more efficacious treatment options.

## Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of No.1 Orthopedics Hospital of Chengdu(approval number 2023–018) and complied with the standards of the Declaration of Helsinki. The Ethics Committee abandoned the informed consent form because it was a retrospective study.

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## Availability of data and material

All data generated or analyzed during this study are included in this article and its supplementary material files. Further enquiries can be directed to the corresponding author (kqqspinee@163.com).

## Code availability

Not applicable.

## Consent for publication

The all authors confirmed that the work described has not been published before and it is not under consideration for publication elsewhere. Its publication has been approved by all co-authors and West China Hospital, Sichuan University and No.1 Orthopedics Hospital of Chengdu.

## Informed consent

Informed consent was obtained from all individual participants included in the study.

## Provenance and peer review

Not commissioned, externally peer-reviewed.

## Animal research (ethics)

This research did not involve animal experiments.

## Plant reproducibility

None.

## CRediT authorship contribution statement

**Jian Tong:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Daoyu Chen:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Jin Li:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Tao Yu:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Haobo Chen:** Writing – original draft, Data curation, Conceptualization. **Qingquan Kong:** Writing – review & editing, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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