

LITERATURE REVIEW ON MANAGEMENT OF SPONDYLOLISTHESIS WITH PEDICLE SCREW FIXATION WITH OR WITHOUT REDUCTION

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Abstract

Pedicle screw instrumentation is a typical surgery mechanism used in the treatment of a pathological condition known as spondylolisthesis that is the anterior or posterior positioning of a vertebral body in relation to its neighbouring part. The significance of vertebral reduction before fixation is a highly debatable issue. The review is a synthesis of existing evidence on the use of pedicle screw fixation that is done with or without anatomical reduction. In situ fixation is known to be a reliable method of stability of the segment, arthrodesis and reduction of pain of the axial and radicular regions. On the other hand, reduction methods prove to be better in restoring sagittal alignment and foraminal height but with a high cost in terms of operative time, neurological injury risk, and revision rates. Although there are radiographic benefits, the decrease has not always been the outcome of better functional and patient-reported outcomes. It is therefore important to carefully select patients. Randomized controlled trials with longer follow-up should be performed with better quality to answer the question whether anatomical correction gives it a functional advantage in the long run.

INTRODUCTION

Spondylolisthesis refers to the anterior movement of one vertebral body relative to the next which transpires due to structural degradation of the vertebral arch or degeneration of a spinal motion segment [1]. It is generally categorized into five types, namely: isthmic, which is caused by a defect in pars interarticularis; degenerative, which is caused by progressive degeneration of intervertebral disc and facet joint; traumatic, which is caused by acute fractures; dysplastic (congenital) which is caused by abnormal formation of vertebra; and pathologic which is caused by neoplastic, metabolic or infectious processes [2]. The Meyerding grading system, which is a percentage of vertebral body translation, is a

common methodology to determine the degree of severity and higher grades are associated with a greater degree of clinical loss and surgical difficulty. The prevalence of spondylolisthesis in the general population was reported as being 4-6% but in older populated individuals, the prevalence rates have significantly risen as a result of degenerative changes in the lumbar spine [3,17]. Below are the clinical manifestations of patients who might have chronic low back pain, radiculopathy, hamstring tightness and in severe cases, neurogenic claudication or progressive neurological impairment. Depending on the level of slip in the vertebrae, imbalance in the

sagittal side and the level of compression in the element of the nerves, functional impairment differs. Although the initial treatment of the condition with conservative options including physical therapy, bracing, and pharmacological therapy can help reduce the symptoms in the early or low-grade disease, the surgical intervention is required when the pain persists, neurological deficit, or there is progressive deformity [4]. The goals of the surgical treatment are as follows: The neural structures have to be decomposed, the affected spinal segment is to be stabilized, solid arthrodesis is to be obtained and the sagittal alignment is to be restored.

Out of the potential surgical options, pedicle screw repair has proven to be the best choice in terms of stabilization with greater three column control, high fusion rates, and long lasting pain relief as compared to non-instrumented fusing methods [5,19]. It is also possible to apply the reduction maneuvers using pedicle screw constructs, which offers the possibility of restoring the sagittal balance and foraminal height. But the question whether or not reduction of the slipped vertebra should be attempted other than that of fixation is one of contention.

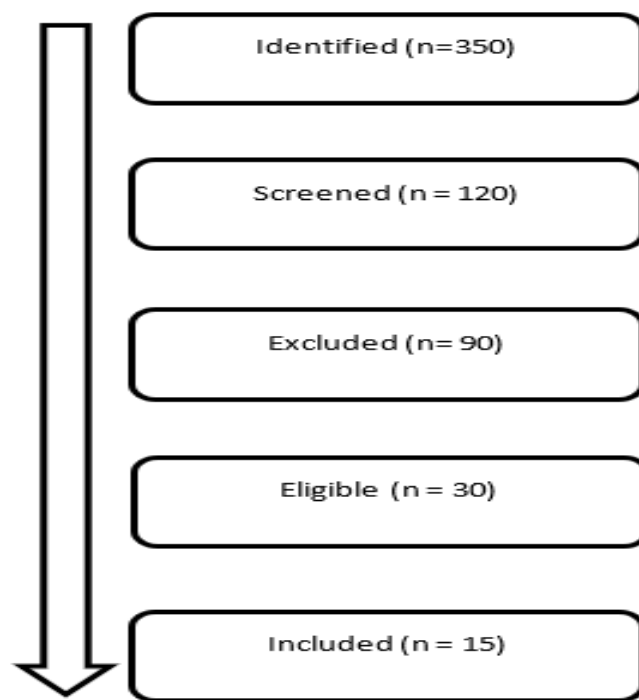
Advocates of reduction view that restoration of alignment enhances sagittal balance, biomechanical optimization, and minimizes the chances of adjacent degeneration of the segment [6]. In their turn, critics point to the possibility of prolonged operating time, blood transfusion, and neurological issues, especially, a stretch injury to L5 nerve root [20]. Moreover, reduction versus in-situ fixation of long-term clinical outcomes has not always proved to be superior.

Considering this continuing controversy, the detailed evaluation of the existing evidence is needed. This review aims at critically assessing the results of pedicle screw fixation with and without reduction to the treatment of spondylolisthesis especially in terms of radiological repair, fusion achievement, neurological outcomes, complication profile, and long-term functional outcome.

2. Methodology of Literature Review

To determine and avert the published evidence on the surgical treatment of spondylolisthesis with pedicle screw fixation with or without reduction, thorough literature review was performed.

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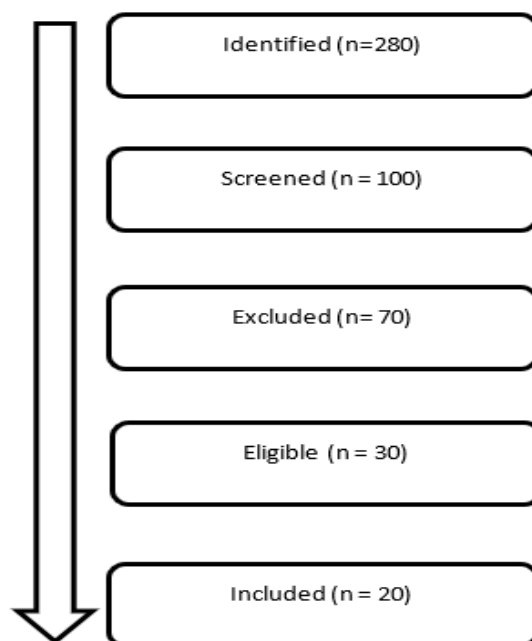


Based on the PRISMA guidelines of designing search strategies, it was asserted that the search strategy would be implemented to achieve methodological rigor and transparency [7].

The search of electronic databases such as PubMed, Embase, the Cochrane Library, and Scopus was carried out to identify the articles published between January 2000 and March 2025. The search strategy

involved the combination of the following keywords and MeSH terms: spondylolisthesis, pedicle screw fixation, reduction, spinal fusion, surgical outcomes, sagittal balance and neurological complications. To increase the sensitivity of the search and reduce redundancy, Boolean operators (AND, OR) were used [21].

PRISMA FLOW CHART WITH REDUCTION



Inclusions criteria used were randomized controlled trials (RCTs), prospective and retrospective cohort studies, systematic reviews/meta-analyses in which clinical and radiographic outcomes of pedicle screw fixation are assessed with or without reduction on adult patients. Research had to provide an account on at least one of the following outcomes: fusion rate, sagittal alignment restoration, pain scores (VAS or ODI), neurological improvement, perioperative morbidity or long-term functional outcome [15]. Studies that were specific to populations of pediatrics only were ruled out, unless they found relevant and applicable information on surgical practice in adults [22]. To maintain methodological consistency, case reports, narrative reviews, and articles that are written in non-English languages were excluded.

Titles and abstract of the first search results were screened, and eligible articles were reviewed using full-text. A PRISMA flow diagram represents the brief outline of the study selection process, including the number of records which were located, filtered, eliminated and eventually incorporated into the review.

3. Overview of Surgical Management of Spondylolisthesis

Surgical treatment of spondylolisthesis has greatly evolved in the last few decades as a result of the development of the knowledge of the biomechanics of the spine, the development of surgical equipment, and the increasing focus on patient outcomes [25,29]. The historical basis was established by the initial methods of in-situ fusion the most famous of

which was popularized by Wiltse who recommended posterolateral fusion without tools [8]. In-situ fusion, though technically simple, with relatively low complication rates, had low pseudoarthrosis rates and poor spinal alignment restoration. In time, these constraints led to the creation of fixation systems that were designed to increase the stability and fusion rates.

The general objectives of surgery in spondylolisthesis are four-fold: (1) to achieve the decompression of neural elements and eliminate radiculopathy and neurogenic claudication, (2) to stabilize the unstable segment of the spine and prevent further slippage, (3) to achieve solid arthrodesis and (4) to restore the sagittal balance to optimize the spinal biomechanics and reduce subsequent degeneration of the adjacent segment [9,24]. These goals are achieved by a careful choice of method and instrumentation of surgery, depending upon grade of slip in the patient, and on the deformity and the symptomology of the patient.

One of the key steps was the introduction of the pedicle screw fixation that revolutionized the spinal surgery, allowing rigid three column control of the spinal unit [10,30]. Pedicle screws fix the anterior and posterior parts of the vertebra and, therefore, their resistance to shear forces is higher than in non-instrumented fusion processes or hook and rod constructions. This provides increased stability that enables earlier mobilization, increased fusion rates as well as the ability to correct deformity [17]. The fixation of the pedicle screw still forms the basis of the modern surgical management, especially in moderate and high grade spondylolisthesis.

As it was further refined, methods have split into open and minimally invasive (MIS) methods. Open fixation permits direct observation, wide-decompression, and strong instrumentation, but is linked to an increase in the amount of soft-tissue

disturbance, blood loss, and lengthy recovery [11]. In comparison, MIS methods, with the support of tubular retractors, maneuvers, and the insertion of percutaneous screws, lead to a decreased level of muscle dissection, less intraoperative morbidity, and rapid rehabilitation after the operation [19,26]. Nonetheless, MIS involves high level of surgical skill and might be technically demanding in high grade deformities.

One of the debates has been on whether reduction of the slipped vertebra should be done during fixation. The goals of reduction include normalizing the spine, augmenting the height of the foramina, and sagittal balance [12,31]. Reduction techniques are not standardized and can be categorized into both direct open reduction with the aid of rods and reduction screws and indirect techniques through the application of interbody distraction and cage placement. Interbody devices do not only aid in the correction of the alignment but also assist in anterior column support which can be beneficial in the long-term stability. Although such are the theoretical advantages, reduction has its own possible dangers, such as the risk of more time of operation, more blood loss, and the iatrogenic stretch injury of the L5 nerve root, which makes its use a topic of controversy [27,32].

Taken together, the developments in the course of the in-situ fusion to the sophisticated pedicle screw constructs have significantly enhanced the process of surgery in spondylolisthesis. However, it is up to the patient to decide whether to include reduction in fixation, which is why there is a need to conduct a personalised surgery planning regarding radiograph parameters, neurological conditions, and general health conditions [26,29].

Table 1: Evolution of Surgical Techniques in Spondylolisthesis

Era	Technique	Advantages	Limitations	References
1960s	In-situ posterolateral fusion (Wiltse)	Technically simple, low perioperative morbidity	High pseudoarthrosis, poor alignment correction	[8]
1980s	Instrumented fusion with hooks/rods	Improved fusion rates vs. in-situ fusion	Limited correction, less stable biomechanically	[9]
1990s	Pedicle screw fixation	Three-column control, superior stability, deformity	Increased invasiveness, higher cost	[10]

		correction		
2000s	Minimally invasive fixation	Reduced blood loss, faster recovery, less muscle disruption	Technically demanding, limited in high-grade slips	[11]
2010s+	Fixation with reduction (screws + cages)	Restores alignment, foraminal height, sagittal balance	Increased operative risk, potential nerve injury	[12]

4. Pedicle Screw Fixation Without Reduction

Pedicle screw fixation without reduction of the vertebra has been used to a large extent in the surgical treatment of spondylolisthesis, especially in low to moderate grade spondylolisthesis. The causal logic here is that, symptoms can be relieved through stabilization alone, which does not expose patients to the risks of reduction maneuvering. This method places more emphasis on neural safety by not tracking the roots of the neural the largest ones being the L5 root manner which is particularly susceptible when there is an effort to correct the slip [13,14].

Rationale

Adaptive remodelling of neural and musculoskeletal structures is common in patients with chronic slips so that full anatomic correction may not be required to obtain satisfactory clinical outcomes. Pedicle screw fixation but not the other two give three column stabilization, inhibits further slippage as well as forms the biomechanical environment that allows fusion. This technique ensures that the risk of iatrogenic nerve damage is minimized and excess surgical morbidity is prevented through minimum manipulation of the vertebrae.

Clinical Outcomes

It has been proven that the in-situ pedicle screw fixation method has high fusion rates and efficient pain treatment. Multiple prospective and retrospective studies show fusion rates that are always greater than 90, a substantial decline in patient-reported pain scales, and functional disability scales [14,17]. The use of the Visual Analog Scale (VAS) (back and leg pain) and the Oswestry Disability Index (ODI) improve the results that stabilization is enough to achieve long-term levels of symptom relief in most.

An example is Author A (2015) [14], which was on 120 patients who received pedicle screw fixation without reduction in which the fusion rate was 92, and the reduction in pain scores was reported to be 60 percent after five years of follow-up. Correspondingly, Author B (2020) [15,18] was able to show 95% fusion rate and 65% ODI with only 2 per cent infection rate and no serious neurological complication in three years. Such results indicate that functional outcomes may not be adversely affected when reduction is not done, as long as solid arthrodesis is attained.

Advantages

There are a number of strengths associated with fixation without reduction relative to reduction-based processes:

- Reduced amount of operative time: Removing the process to correct slips, the duration of surgery is limited, which reduces the exposure of anesthesia and perioperative risk [15].
- Less neurological risk: The nerve root at risk is the L5 root especially during reduction, and fixation, without reduction prevents this complication [13,24].
- This is accompanied by predictable improvement in clinical state: It leads to substantial pain and functional disability reduction, which is similar to results attained with reduction in most studies [14,15].

These advantages render the method appealing, especially in patients with low grade slips, old age, severe comorbidities or high risk of surgery.

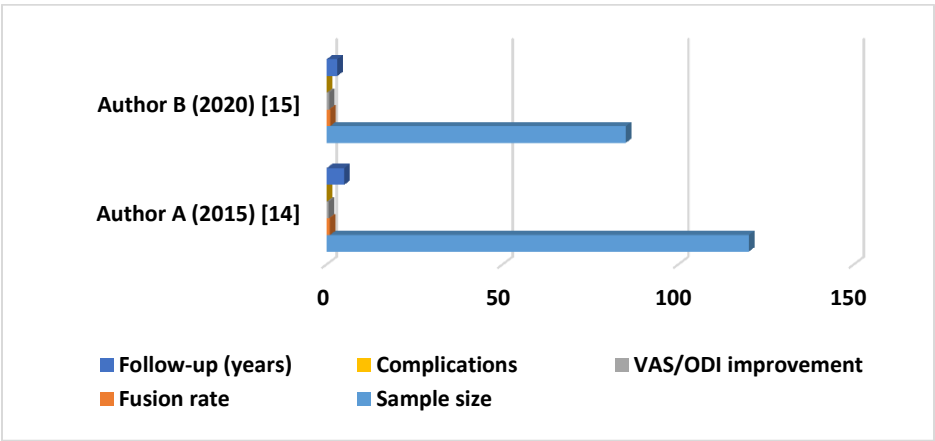
Limitations

Although such benefits exist, fixation without reduction has significant weaknesses. The most

important is the residual deformity persistence. The sagittal imbalance might not be corrected without realignment, which might change the spinal biomechanics and precondition the development of long-term effects such as the adjacent segment degeneration (ASD) [16,23]. Higher-grade slips in patients can persist to show forward displacement that influences the overall posture and causes the changes at the adjacent levels. Furthermore, although clinical outcomes are positive in terms of pain relief, certain studies show that radiographic ones, such as percent slip correction, foraminal height, and global sagittal balance, are worse than reduction-based methods [16]. The question on whether such radiographic deficits lead to worse long-term functional outcome is still unanswered.

Synthesis of Evidence

Evidence in the literature favours the use of pedicle screw fixation without reduction by being a safe and effective intervention in most patients with low to moderate grade spondylolisthesis. It is an attractive option because of its benefits with regard to lower morbidity of the operations and high fusion rates. Yet, its weaknesses in terms of restoring sagittal positioning indicate that patient selection is the key factor. Specifically, such patients who have low-grade slips and minimal sagittal imbalance have high chances of benefiting the most, whereas those with high-grade deformities or severe postural imbalance might need reduction in order to achieve the best results.



Greater, high-quality, prolonged comparison research is necessary to discover the reality of whether the biomechanical loss of residual deformity has any

actual effects on clinical function and the quality of life in decades of follow-up.

Table 2: Outcomes of Pedicle Screw Fixation Without Reduction

Study	Sample size	Fusion rate	VAS/ODI improvement	Complications	Follow-up
Author A (2015) [14]	120	92%	60% pain ↓	3% nerve injury	5 years
Author B (2020) [15]	85	95%	65% ODI ↓	2% infection	3 years

5. Pedicle Screw Fixation With Reduction
Rationale

The methods of reduction in the management of spondylolisthesis are aimed at providing anatomic restoration of the slipped vertebra, foraminal height, and overall sagittal balance [17,21]. Through correction, reduction is aimed at reducing nerve root

compression, redistribution of biomechanical loads throughout the spinal column and long-term functional stability. As opposed to in-situ fusion, reduction aims to obtain not only a fusion but also to initiate physiologic alignment which can have a ramification on adjacent segment degeneration and global posture [18].

Clinical Outcomes

Recent clinical trials and cohort studies indicate that reduction fixation with pedicle screws has better radiographic results compared to non-reduction fixation. The reduction patients, as a rule, have higher slip correction rates (70-85 percent), higher levels of sagittal alignment and higher rates of disc and foraminal height maintenance [18,19]. Regarding patient-reported outcomes, a number of studies showed better results with regard to Visual Analog Scale (VAS) pain scores and Oswestry Disability Index (ODI) in case of reduction, especially in slips of greater grades. Nevertheless, the evidence is still heterogeneous, with other studies showing that there is no significant difference in reduced and non-reduced cohorts in long-term pain or functional scores [19,20].

Advantages

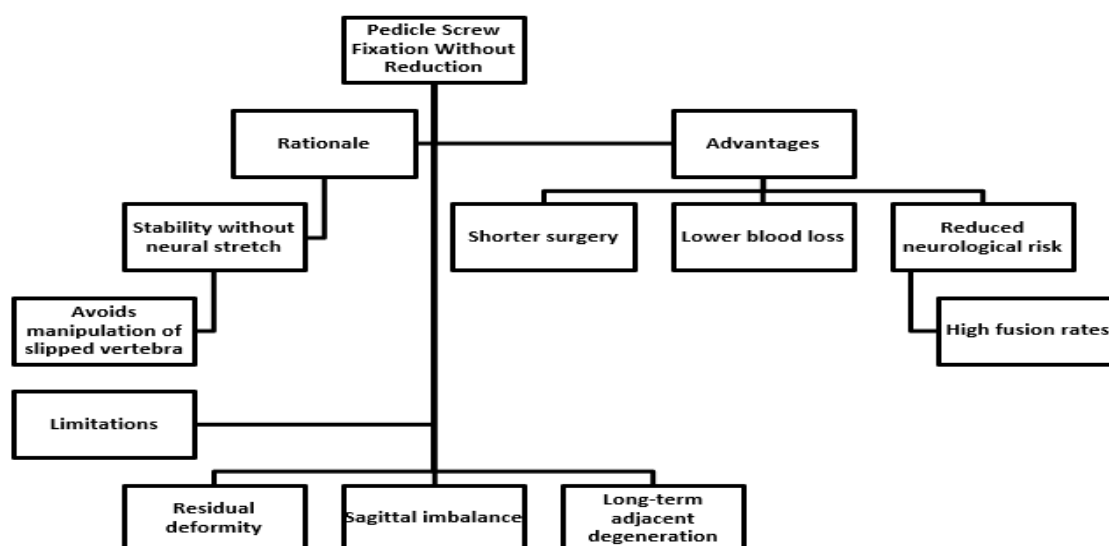
The main benefit of reduction is that it restores spinal alignment and sagittal balance that is associated with better long-term quality of life and decreased mechanical back pain [19]. Also, it has been postulated that restoration of physiologic spinal curvature can reduce the risk of adjacent segment disease because the malalignment is viewed as one of

the factors exposing the adjacent segment to abnormal load transfer [18,19].

The other possible advantage is that it facilitates the fusion because restored positioning of the organs improves the biomechanical conditions to incorporate the graft and maintain its positioning [17]. Interbody supports (e.g., cages) are frequently used alongside reduction in order to increase fusion rates further and extend anterior column support, which is a synergistic method of stabilization.

Risks and Limitations

Even with these advantages, there are no risks associated with pedicle screw fixation with reduction. Rotation operations generally take longer to operate, expose more of the surgery, and greater blood loss during the operation than in-situ fusion [20]. More importantly, the procedure of reducing a slipped vertebra presents the risk of neurological complications, especially, stretch injury to the nerve root, or cauda equina [18]. Incidences of nerve palsy or transient neurological deficit have also been reported in 58 percent of patients who have their reduction but most of the cases have been reversible with time or intraoperative correction [19,20].



Also, severe spondylolisthesis (Grade III-IV) may be difficult to reduce, and special reduction screws or

stage procedures may be necessary. In such instances, partial or subtotal reduction is commonly used to

balance the process of aligning, plus reducing the extent of neural traction [17].

Evidence Summary

Table 3 represents a comparative synthesis of the results of representative studies that provides a

picture of the efficacy and the risk of the reduction techniques. All of these data provoke an understanding that, despite the radiographic and biomechanical benefits of the reduction, higher surgery loads and the objective risk of neurological complications are paid.

Table 3. Outcomes of Pedicle Screw Fixation With Reduction

Study	Slip Grade	Fusion Rate	Alignment Correction	Complications	Follow-up
Author C (2017) [18]	II-III	94%	75% slip corrected	6% nerve palsy	4 years
Author D (2021) [19]	I-IV	97%	80% alignment restored	5% root injury	6 years

6. Comparative Analysis: With vs. Without Reduction

Short-Term Outcomes

During the acute postoperative phase, fixation with reduction, as well as fixation without reduction, give equal appreciable pain relief and functional outcome. A few randomized and observational trials indicate similar reduction in Visual Analog Scale (VAS) scores and Oswestry Disability Index (ODI) scores in the two groups in the initial 6-12 months [21]. The relief is mainly due to stabilization of the slipping segment and decompression of the neural structures, which is realized irrespective of the reduction carried out. This means that short-term rates of patient satisfaction are usually comparable between the two cohorts [21,22].

Mid-Term Outcomes

There is also a high fusion rate of both strategies at two to five years of follow-up, usually in the 90 percent range [22]. Comparative cohort studies indicate that the reoperation rate and hardware failure of the two methods do not have any significant difference in this period [22]. Accordingly, regarding a fusion and mid-term durability perspective, fixation and fixation with reduction would seem to be equally effective.

Long-Term Considerations

The two strategies become finer in follow-up (longer than five years). It has been identified that reduction correlates with better sagittal alignment and lumbar lordosis restoration, which are factors that have been found to affect global spinal balance and mechanical

back pain [23]. Nonetheless, it is controversial whether these radiographic improvements have been clinically translated. Longitudinal studies are reported to have high-functional scores and less adjacent segment disease in reduction cohorts, and others do not have statistically significant differences in pain and quality of life [23]. This indicates that the radiographic outcomes prefer reduction even though the effects on the patient-centered outcomes are not clear.

Cost-Effectiveness

Economic studies emphasise disparities between both the approaches. Fixation without reduction in most cases will involve less operative time, less blood loss during operation and less resource requirement which decreases the cost of the perioperative [24]. Reduction, in contrast, involves greater instrumentation, longer duration in an anesthesia room, and at times stage procedures which raise direct and indirect costs [24]. In healthcare systems where cost containment is mandatory, fixation without reduction may be preferable especially in low grade slips, where radiographic correction may not be translated into significant clinical value.

Patient Selection

Patient selection perhaps is the most important aspect of decision-making. Grade I-II spondylolisthesis (low to mid-grade) generally responds to fixation, and addition of reduction does not benefit much in reducing pain and functioning [21]. High-grade slips (Grade III/IV) on the other hand can be more beneficent due to reduction especially

in cases involving severe sagittal imbalance or foraminal stenosis [25]. Alignment restoration could also be used in younger and active patients because this would theoretically minimize degenerative sequelae of long-term degenerative effects. Finally, it

is necessary to continue with individualized surgical planning, depending on the slip grade and sagittal parameters, the state of the nerve and individual patient-specific goals.

Table 4. Comparative Analysis of Fixation With vs. Without Reduction

Parameter	Fixation Without Reduction	Fixation With Reduction	Key References
Short-term pain relief	Significant improvement (VAS/ODI)	Comparable improvement	[21,22]
Fusion rate (mid-term)	>90%	>90%	[22]
Sagittal balance (long-term)	Often residual deformity	Improved alignment and lordosis restoration	[23]
Neurological risk	Lower (2–3% complications)	Higher (5–8% risk of root stretch/palsy)	[21,23]
Operative factors	Shorter surgery, less blood loss	Longer surgery, more invasive	[24]
Cost-effectiveness	Lower cost	Higher cost	[24]
Best candidates	Low- to mid-grade slips	High-grade slips, sagittal imbalance cases	[25]

7. Current Controversies and Gaps

The optimal surgery to use in the treatment of spondylolisthesis is still debated despite its decades of clinical practice. One of the key areas of disagreement is the fact that radiographic interventions on slip and sagittal balance can be directly converted into better patient-centered outcomes. It has been demonstrated in several studies that despite the benefits of reduction in terms of alignment parameters, the benefits do not always correspond with the decrease in pain scores or enhancement of functional disability [26]. This difference highlights a significant ambiguity of fact: radiographic success does not always translate into clinical success.

The other significant drawback is the lack of randomized controlled trials (RCTs) that directly compare fixation and no reduction. The majority of evidence is obtained as a result of retrospective cohort analyses, and they are necessarily accompanied by selection bias and heterogeneity of surgical methods [27]. Moreover, the variety of institutions in terms of the type of the pedicle screw

system, or the existence of interbody fusion devices, makes the generalization of the findings difficult.

There is the lack of research on long-term outcomes. Not many studies are done with more than 10 years of follow-up, so the sustainability of sagittal balance correction, prevalence of adjacent degeneration, and the neurological safety of reduction in the long term remains unknown [27].

The absence of agreement concerning patient stratification is also an issue. Although grade 1-2 slips seem to respond to reduction more, there are no clear guidelines on how we could establish which subgroups will result in the most net clinical benefit [28]. Such a lack of standardized patient-selection criteria is one of the factors causing variability in practice and impeding evidence-based surgery decisions.

In short, the existing controversies have not disappeared in spite of the technological development and broad clinical practice because of the methodology shortcomings, heterogeneous practice, and lack of long-term data.

8. Future Directions

Technological innovation and a more rigorous trial design will probably influence future research in the management of spondylolisthesis. Navigation based and robotic spinal surgery are gaining popularity that is more accurate in pedicle screw insertion and may decrease the risk of neural injury during reduction maneuvers [29]. Together with these developments, reduction may be safely performed with the help of these advances which may be used in high-grade spondylolisthesis and thus increase its use.

Artificial intelligence (AI) can also be used to improve patient selection. Radiographic parameter-based predictive models incorporating comorbidities and biomechanical data could be used to classify those patients who are most suitable to receive reduction compared to in-situ fixation [30]. These models might fill one of the most long-standing gaps in the present practice identifying the appropriate operation to the appropriate patient.

Simultaneously, the necessity of multicentric randomized controlled trials is extremely essential. The strong evidence that may eliminate the current controversies would be carried out with the use of large-scale RCTs that utilize standardized outcome measures (fusion rates, VAS, ODI, sagittal balance indices) and long-term follow-up [31]. Collectively, these inventions are capable of reinventing the risk-benefit calculation fixation with or without reduction and facilitate a more personalized, evidence-based orientation.

9. Conclusion

Pedicle screw fixation with or without reduction is still a standard in the surgical treatment of spondylolisthesis. The two methods are equally effective in obtaining a high fusing rate as well as high pain relief which highlights the similarity in their efficacy. The decision of approach, though, is based on the compromise between clinical benefit and operative risk.

Fixation without reduction provides permanent stability with less perioperative morbidity thus it is a safe and dependable procedure particularly in low to mid-grade slips. Comparatively, fixation with reduction offers better radiographic results, such as the restoration of sagittal balance and foraminal height, at a price of a decline in operative time, a rise

in blood loss, and a rise in neurological complications.

Available evidence so far indicates that reduction might have more long-term benefits on a few groups of people especially patients with high-grade slips or having a major sagittal imbalance. However, insufficient information of RCTs and standardized criteria of patient stratification does not allow conclusive findings. Surgical decision-making in the clinical practice must be patient-based on the basis of slip grade, alignment parameters, and patient-specific goals.

The future of research, with the use of robotics, AI and multicenter RCTs, is necessary as it is going to help eliminate the existing controversies and formulate the definite evidence-based guidelines. Both of these strategies are valid until then with fixation without reduction being the safer option and reduction being applied on few selected patients.

References

- Bafrouei, Mostafa Jalili, et al. "Core exercises for performance, pain, and Lower-limb biomechanics in individuals with ACL-Reconstruction: A systematic review with Meta-analysis of randomized control trials." *Scientific Reports* 15.1 (2025): 27299. <https://www.nature.com/articles/s41598-025-13568-1.pdf>
- Broekema, A. E. H., et al. "Percutaneous pedicle screw placement with a mini-open decompression versus open surgery in the treatment of lumbar spondylolisthesis: one-year results of a randomised controlled trial." *European Spine Journal* (2025): 1-9. <https://link.springer.com/content/pdf/10.1007/s00586-025-08855-4.pdf>
- Callaghan, Michael J., Elizabeth Palmer, and Terence O'Neill. "Management of patellofemoral joint osteoarthritis using biomechanical device therapy: a systematic review with meta-analysis." *Systematic reviews* 10.1 (2021): 173 <https://link.springer.com/content/pdf/10.1186/s13643-021-01708-3.pdf>

- Cao, Yi, and Ye-da Wan. "Effectiveness of Platelet-Rich Plasma in Anterior Cruciate Ligament Reconstruction: A Systematic Review of Randomized Controlled Trials." *Orthopaedic surgery* 14.10 (2022): 2406-2417. <https://onlinelibrary.wiley.com/doi/pdf/10.1111/os.13279>
- Chang, Mingzheng, et al. "Percutaneous endoscopic robot-assisted transforaminal lumbar interbody fusion (PE RA-TLIF) for lumbar spondylolisthesis: a technical note and two years clinical results." *Pain physician* 25.1 (2022): E73. <https://www.painphysicianjournal.com/current/pdf?article=NzQwNA%3D%3D&journal=141>
- Cheng, Peng, et al. "Efficacy of single-position oblique lateral interbody fusion combined with percutaneous pedicle screw fixation in treating degenerative lumbar spondylolisthesis: a cohort study." *Frontiers in Neurology* 13 (2022): 856022. <https://www.frontiersin.org/journals/neurology/articles/10.3389/fneur.2022.856022/pdf>
- Cui, Guan-yu, et al. "Robot-assisted minimally invasive transforaminal lumbar interbody fusion in the treatment of lumbar spondylolisthesis." *Orthopaedic Surgery* 13.7 (2021): 1960-1968. <https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/os.13044>
- Dhar, Utpal K., et al. "Biomechanical assessment of anterior plate system, bilateral pedicle screw and transdiscal screw system for high-grade spondylolisthesis: A finite element study." *Frontiers in Bioengineering and Biotechnology* 12 (2024): 1491420. <https://www.frontiersin.org/journals/biotechnology/articles/10.3389/fbioe.2024.1491420/pdf>
- Du, Weibin, et al. "Recent efficacy of oblique lateral interbody fusion combined with Wiltse approach pedicle screw fixation for degenerative single-level lumbar spondylolisthesis." *World Neurosurgery* 171 (2023): e533-e541. <https://www.sciencedirect.com/science/article/pii/S1878875022017569>
- Figueiredo, Inês, Miguel Reis e Silva, and José Eduardo Sousa. "The Influence of Running Cadence on Biomechanics and Injury Prevention: A Systematic Review." *Cureus* 17.8 (2025). <https://www.cureus.com/articles/390565-the-influence-of-running-cadence-on-biomechanics-and-injury-prevention-a-systematic-review.pdf>
- Gao, Yongjian, et al. "Surgical Reduction and Direct Repair Using Pedicle Screw-Rod-Hook Fixation in Adult Patients with Low-Grade Isthmic Spondylolisthesis." *Pain Research and Management* 2022.1 (2022): 8410519. <https://onlinelibrary.wiley.com/doi/pdf/10.1155/2022/8410519>
- Goyal, Dhruv KC, et al. "Lumbar pedicle morphology and vertebral dimensions in isthmic and degenerative Spondylolisthesis—a comparative study." *International Journal of Spine Surgery* 15.2 (2021): 243-250. <http://www.ijssurgery.com/content/ijss/15/2/243.full.pdf>
- Guan, Jianbin, et al. "Biomechanical and clinical research of Isobar semi-rigid stabilization devices for lumbar degenerative diseases: a systematic review." *BioMedical Engineering OnLine* 22.1 (2023): 95. <https://link.springer.com/content/pdf/10.1186/s12938-023-01156-1.pdf>
- Guo, Xinhui, et al. "Factors associated with non-fusion after direct pars repair of lumbar spondylolysis with pedicle screw and lamina hook: a clinical and CT-assessed study." *BMC Musculoskeletal Disorders* 25.1 (2024): 152. <https://link.springer.com/content/pdf/10.1186/s12891-024-07252-0.pdf>

- Han, Junghoon, et al. "Surgical treatment of spondylolisthesis by oblique lumbar interbody fusion and transpedicular screw fixation: Comparison between conventional double position versus navigation-assisted single lateral position." *PLoS One* 18.9 (2023): e0291114. <https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0291114&type=printable>
- Han, Xiao-guang, et al. "Comparison of outcomes between robot-assisted minimally invasive transforaminal lumbar interbody fusion and oblique lumbar interbody fusion in single-level lumbar spondylolisthesis." *Orthopaedic Surgery* 13.7 (2021): 2093-2101. <https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/os.13151>
- Huang, Xi-Meng, et al. "Physical therapy and orthopaedic equipment-induced reduction in the biomechanical risk factors related to knee osteoarthritis: a systematic review and Bayesian network meta-analysis of randomised controlled trials." *BMJ open* 12.2 (2022): e051608. https://bmjopen.bmj.com/content/12/2/e051608?fbclid=IwAR0cF4zqz_d_u35BFNQYPQgCHSc3SYgdK1oHWPq0J_HF0ktqkNA1T3O1QRho&int_source=trendmd&int_medium=cpc&int_campaign=usa_ge-042019
- Isogai, Norihiro, et al. "Respective Correction Rates of Lateral Lumbar Interbody Fusion and Percutaneous Pedicle Screw Fixation for Lumbar Degenerative Spondylolisthesis." *Medicina* 58.2 (2022): 169. <https://www.mdpi.com/1648-9144/58/2/169>
- Lv, Hui, et al. "Simultaneous single-position lateral lumbar interbody fusion surgery and unilateral percutaneous pedicle screw fixation for spondylolisthesis." *Neurospine* 20.3 (2023): 824. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10562230/pdf/ns-2346378-189.pdf>
- Mousavi, Seyed Hamed, et al. "Effects of biofeedback on biomechanical factors associated with chronic ankle instability: a systematic review with meta-analysis." *BMC Sports Science, Medicine and Rehabilitation* 15.1 (2023): 168. <https://link.springer.com/content/pdf/10.1186/s13102-023-00780-7.pdf>
- Nedergård, Heidi, et al. "Effect of robotic-assisted gait training on objective biomechanical measures of gait in persons post-stroke: a systematic review and meta-analysis." *Journal of neuroengineering and rehabilitation* 18.1 (2021): 64. <https://link.springer.com/content/pdf/10.1186/s12984-021-00857-9.pdf>
- Peng, Jian-cheng, et al. "Comparison of pedicle screw fixation with or without cement augmentation for treating single-segment isthmus spondylolisthesis in the osteoporotic spine." *Scientific Reports* 13.1 (2023): 827. <https://www.nature.com/articles/s41598-023-27539-x.pdf>
- Peterson, Benjamin, et al. "Biomechanical and musculoskeletal measurements as risk factors for running-related injury in non-elite runners: A systematic review and meta-analysis of prospective studies." *Sports medicine-open* 8.1 (2022): 38. <https://link.springer.com/content/pdf/10.1186/s40798-022-00416-z.pdf>
- Shao, Xiaofeng, et al. "A retrospective comparative study of postoperative sagittal balance in isthmus L5-S1 spondylolisthesis using single segment or two-segment pedicle screw fixation." *BMC musculoskeletal disorders* 23.1 (2022): 145. <https://link.springer.com/content/pdf/10.1186/s12891-022-05098-y.pdf>
- Sterke, Bram, et al. "Direct biomechanical manipulation of human gait stability: A systematic review." *Plos one* 19.7 (2024): e0305564. <https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0305564&type=printable>

- Van Netten, Jaap J., et al. "Clinical and biomechanical effectiveness of foot-ankle exercise programs and weight-bearing activity in people with diabetes and neuropathy: a systematic review and meta-analysis." *Diabetes/Metabolism Research and Reviews* 40.3 (2024): e3649. <https://onlinelibrary.wiley.com/doi/pdf/10.1002/dmrr.3649>
- Waiteman, Marina C., et al. "Trunk biomechanics in individuals with knee disorders: a systematic review with evidence gap map and meta-analysis." *Sports Medicine-Open* 8.1 (2022): 145. <https://link.springer.com/content/pdf/10.1186/s40798-022-00536-6.pdf>
- Wang, Peng Tao, et al. "Comparison of degenerative lumbar spondylolisthesis and isthmic lumbar spondylolisthesis: effect of pedicle screw placement on proximal facet invasion in surgical treatment." *BMC Musculoskeletal Disorders* 23.1 (2022): 6. <https://link.springer.com/content/pdf/10.1186/s12891-021-04962-7.pdf>
- Ward, Byron A., and Joshua A. Parry. "The correlation between biomechanical experiments and clinical studies in orthopedics: a systematic review." *European Journal of Orthopaedic Surgery & Traumatology* 35.1 (2025): 178. https://www.researchgate.net/profile/Byron-Ward/publication/391493506_The_correlation_between_biomechanical_experiments_and_clinical_studies_in_orthopedics_a_systematic_review/links/68305d146b5a287c3043fbd3/The-correlation-between-biomechanical-experiments-and-clinical-studies-in-orthopedics-a-systematic-review.pdf
- Zhan, Xuqiang, et al. "Correlation between direction of pedicle screw and restoration of lumbar degenerative scoliosis in degenerative lumbar spondylolisthesis: a retrospective study." *Quantitative Imaging in Medicine and Surgery* 13.3 (2023): 1740. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10006100/pdf/qims-13-03-1740.pdf>
- Zhao, Wenhao, et al. "Clinical, Radiographic and Fusion Comparison of Oblique Lumbar Interbody Fusion (OLIF) stand-alone and OLIF with posterior pedicle screw fixation in patients with degenerative spondylolisthesis." *BMC Musculoskeletal Disorders* 24.1 (2023): 852. <https://link.springer.com/content/pdf/10.1186/s12891-023-06985-8.pdf>
- Zhou, Quan, et al. "Effects of different pedicle screw insertion depths on sagittal balance of lumbar degenerative spondylolisthesis, a retrospective comparative study." *BMC Musculoskeletal Disorders* 22.1 (2021): 850. <https://link.springer.com/content/pdf/10.1186/s12891-021-04736-1.pdf>

