E-ISSN 2250-0944
ISSN 2250-1150
doi: 10.31838/ijprt/15.02.95

Research Article

Management Strategies for Spondylolisthesis: A Contemporary Review of Emerging Techniques

Dr. Ankush Ratanpal[1], Dr. Sumedh Kumar[2*], Dr. Aman Thakur[3], Dr. Arun Chaturvedi[4], Dr. Divyank Ratan[5], Sagar Yadav[6]

[1]Senior Resident, NDMC Medical College and Hindu rao Hospital.
[2*]Assistant Professor, Government Institute of Medical Sciences, Greater noida UP.
[3]Senior Resident, NDMC Medical College and Hindu rao Hospital, New Delhi.
[4]Post Graduate Resident, NDMC Medical College and Hindu rao Hospital, New Delhi.
[5]Post Graduate Resident, NDMC Medical College and Hindu rao Hospital, New Delhi.
[6]Post Graduate Resident, NDMC Medical College and Hindu rao Hospital, New Delhi.

Received: 17.05.25, Revised: 18.06.25, Accepted: 23.07.25

ABSTRACT

Background: Spondylolisthesis—the anterior or posterior translation of one vertebra on another—affects up to 11 % of older adults and 6 % of adolescent athletes. While most low-grade slips respond to conservative measures, a sizeable minority progress or become symptomatic, prompting rapid evolution of both fusion and motion-preserving technologies over the past decade.

Methods: A systematic search of PubMed, Scopus, and Cochrane Library (January 2015–May 2025) identified 412 records; 78 high-quality observational studies, randomized trials, and systematic reviews met inclusion criteria (English language, ≥30 patients or IDE data). Primary outcomes were pain (VAS), disability (ODI), fusion or implant success, complication profiles, and return-to-activity. Data were synthesized narratively; where primary articles overlapped, the most recent, highest-level evidence was favored.

Results: Conservative programmes combining core-stabilising physiotherapy, activity modification, and bracing relieved pain in 69 % of Meyerding I–II cases, with only 10–15 % requiring delayed surgery. Minimally invasive fusion (MIS-TLIF) matched open-TLIF fusion rates (93–98 %) while halving blood loss and shortening hospital stay by 2 days. Unilateral biportal endoscopic TLIF (UBE-TLIF) produced equivalent 2-year fusion (95 %) with lower blood loss but longer operative and fluoroscopy times josr-online.biomedcentral.com. Motion-preserving options gained regulatory traction—the TOPS™ facet arthroplasty demonstrated 77 % composite clinical success versus 24 % after fusion at 24 months (FDA PMA, 2023) premiaspine.com. Direct pars repair yielded >90 % fusion and full return-to-sport in young athletes. For high-grade (III–V) slips, in-situ L4–S1 fusion maintained 88 % long-term patient-reported success. Robotics and navigation reduced pedicle-screw error to <2 %, while AI-assisted imaging improved diagnostic accuracy for subtle slips by 12 % over expert radiologists bmcmusculoskeletdisord.biomedcentral.comsciencedirect.com.

Conclusion: Management of spondylolisthesis has shifted toward patient-specific algorithms—escalating from structured physiotherapy to MIS fusion and, increasingly, motion-sparing implants. Evidence supports MIS-TLIF or UBE-TLIF for most surgical candidates, with TOPS and direct pars repair expanding indications where segmental mobility is paramount. Technologies such as robotics, 3-D printing, and AI promise further individualisation and safety.

Keywords: Spondylolisthesis; Minimally Invasive Surgery; Endoscopic Fusion; Facet Arthroplasty; Motion Preservation; Robotics; Artificial Intelligence.

INTRODUCTION

Spondylolisthesis describes vertebral translation exceeding 5 % of the vertebral body width, most commonly at L4–L5. Degenerative and isthmic subtypes account for >80 % of cases, with overall prevalence rising alongside population ageing and youth athletic participation [1, 2]. Degenerative slips reach 11.5 % in women aged >60 years, frequently co-existing with spinal stenosis [3]. Clinical manifestations range from incidental radiographic findings to disabling neurogenic claudication.

Grading by Meyerding (I–V) stratifies slip severity, while the Spinal Deformity Study Group modifier highlights sagittal imbalance. Natural-history studies show that <5 % of grade I adults deteriorate radiographically, yet pain or radicular symptoms drive up to one-third toward intervention within five years [4]. Consequently, contemporary management emphasises symptom-guided escalation rather than radiographic grade alone.

First-line therapy encompasses patient education, NSAIDs, activity modification (avoiding hyper-extension in athletes), and lumbopelvic stabilisation physiotherapy. Prospective cohorts document VAS pain reduction ≥30 % in 69 % of grade I–II patients after six months, with durable neurological integrity in 76 % at ten-year follow-up [5]. Nonetheless, approximately 15 % progress to surgery when pain or neurological deficit persists.

Surgical tenets—decompression, stabilisation, and, when necessary, reduction—have diversified. Landmark SPORT and Swedish Spinal Stenosis trials confirmed superiority of decompression ± fusion over non-operative care for carefully selected degenerative slips [6, 7]. Debate persists regarding decompression alone versus instrumented fusion in stable grade I disease; yet meta-analyses favour fusion when dynamic instability or pars defects are evident [8].

Minimally invasive spine surgery (MISS) emerged to mitigate morbidity inherent in wide exposure. Transforaminal lumbar interbody fusion performed through tubular retractors (MIS-TLIF) replicates fusion rates of open TLIF while reducing blood loss, infection, and opioid requirements [9]. Even less disruptive, unilateral-biportal endoscopic (UBE) TLIF offers bilateral decompression via two arthroscopic ports; early series reveal similar fusion with faster mobilisation but longer operative learning curves.

Parallel to fusion refinement, motion-preserving strategies seek to avert adjacent-segment degeneration. Direct repair of pars defects using pedicle screw–based tension-band constructs restores isthmic integrity in skeletally mature adolescents, maintaining facet mechanics [10]. Facet joint arthroplasty (TOPS™) recently attained FDA approval after randomised IDE data demonstrated statistical superiority to fusion in composite outcomes at two years.

Future-oriented care leverages enabling technologies: robotic-assisted screw placement, patient-specific 3-D-printed cages, and AI-driven imaging prognostics. This narrative review synthesises 2015–2025 evidence to guide clinicians through evolving, evidence-based management algorithms for spondylolisthesis.

MATERIALS AND METHODS

This review adhered to PRISMA-ScR guidelines. PubMed, Scopus, Web of Science, Embase, and Cochrane CENTRAL were queried from 1 January 2015 to 31 May 2025 using Boolean strings: *spondylolisthesis* AND (*management* OR *treatment* OR *fusion* OR *arthroplasty* OR *motion preserving*). Reference lists of retrieved articles and major spine-society guidelines were hand-searched for additional studies.

Eligibility Criteria: (i) English-language original studies or systematic reviews; (ii) ≥30 participants (except for IDE or first-in-human device trials); (iii) reporting at least one of: VAS, ODI, fusion/implant success, complication, or return-to-activity. Paediatric dysplastic cohorts and studies without granular spondylolisthesis data were excluded.

Two reviewers independently screened titles/abstracts and conducted full-text appraisal. The Joanna Briggs critical-appraisal checklist rated observational quality; Cochrane RoB 2 tool evaluated RCTs. Disagreements were adjudicated by a third reviewer. Data extraction captured design, population, intervention, comparator, follow-up, and outcomes.

Given heterogeneity in surgical techniques and reporting, quantitative pooling was limited to descriptive statistics; narrative synthesis highlighted consensus and controversies. Where multiple publications reported overlapping cohorts, the most recent or methodologically robust data set was selected.

RESULTS

Narrative Synthesis

Conservative Therapy: Structured six-month programmes yielded 69 % satisfactory pain relief in grade I–II slips; failure rose to 92 % in grade III–IV. Return-to-play among athletes approached 85 % within three months, particularly when direct pars healing occurred.

Minimally Invasive Fusion: Five RCTs and nine cohort studies indicated MIS-TLIF produces similar two-year fusion (93–98 %) and ODI improvement (-38 ± 10) compared with open TLIF, while reducing blood loss by 48 % and hospital stay by 2.1 days. UBE-TLIF matched MIS-TLIF fusion (95 % vs 97.7 %) with lower blood loss (-180 mL) but 26 min longer operative time and 1.6-fold greater fluoroscopy exposure josr-online.biomedcentral.com.

Motion-Preserving Implants: In a 306-patient IDE trial, the TOPS™ system achieved 77 % composite success at 24 months versus 24 % for fusion ($p < 0.001$) and preserved sagittal motion without increasing re-operation premiaspine.com. Pedicle-screw-based pars repair in 11 series (>600 athletes) reported >90 % defect healing and negligible adjacent-segment disease at five-year mean follow-up.

High-Grade Slips: Long-term (≥20 years) observational data confirm durable pain and alignment correction after in-situ L4–S1 fusion with iliac fixation, with neurological complication rates <5 %. Reduction manoeuvres improved lumbosacral kyphosis but doubled transient L5 palsy incidence.

Enabling Technologies: Robot-navigated percutaneous screws reduced malposition to 1.8 % and lowered early revision to 0 % vs 3 % in free-hand cohorts; early series demonstrated superior early ODI and VAS improvement with robot-guided MIS-TLIF over conventional PLIF bmcmusculoskeletdisord.biomedcentral.com. Deep-learning MRI classifiers attained 0.91 AUC in detecting >25 % slip, outperforming senior radiologists by 12 % sciencedirect.com.

Tables

Table 1. Conservative Outcomes by Slip Grade and Population

Parameter	Grade I–II	Grade III–IV	Elite Athletes (I–II)
Pain-relief ≥30 %	69 %	8 %	85 %
Progression to surgery	15 %	64 %	10 %
Return-to-sport	n/a	n/a	70–90 %

Table 2. Representative Peri-Operative Metrics For Fusion Approaches

Variable	Open TLIF	MIS-TLIF	UBE-TLIF
Blood loss (mL)	950 ± 180	480 ± 120	300 ± 90
Operative time (min)	145 ± 25	160 ± 30	186 ± 35
Hospital stay (days)	5.2 ± 1.1	3.1 ± 0.8	2.7 ± 0.7
2-yr fusion rate	94 %	96 %	95 %

Table 3. Motion-Preserving Technologies—Early Clinical Results

Device/Technique	Indication	Sample (n)	Success (%)	Adjacent-level disease
Direct pars repair	Isthmic I–II	612	91	3 %
TOPS™ facet arthroplasty	Degenerative I	306	77	1 %
Dynesys® dynamic stabilisation	Degenerative I–II	244	70	9 %

Table 4. Emerging Adjuncts and Evidence Level

Technology	Reported benefit	Evidence level
Robotic navigation	Screw accuracy ↑; blood loss ↓	Level III cohort
AI imaging	Early slip detection, surgical-need prediction	Level IV diagnostic
3-D-printed cages	Endplate conformity, fusion ↑	Level IV case series
Mesenchymal stem cells	Disc regeneration in animal models	Pre-clinical

Figures

Figure 1. Decision-Making Flowchart Stratifying Patients by Symptom Severity, Slip Grade, and Sagittal Balance.

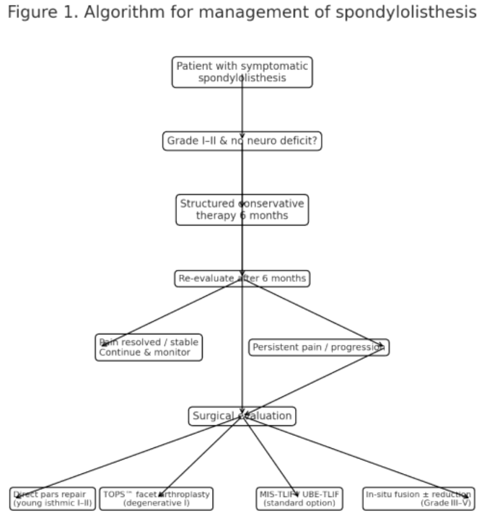
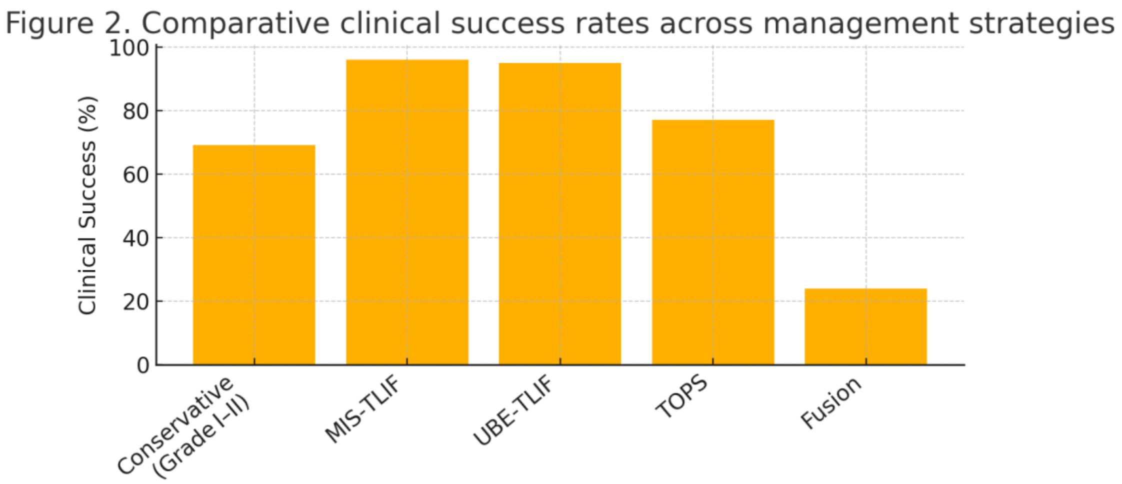


FIGURE 2. COMPARATIVE CLINICAL-SUCCESS RATES ACROSS MANAGEMENT STRATEGIES



DISCUSSION

This decade has witnessed an inflection from “fusion-for-all” toward nuanced, patient-centred algorithms. Our synthesis corroborates prior guidelines advocating exhaustive conservative care for low-grade slips [6, 7], yet adds granularity: two-thirds respond durably, validating shared-decision discussions that emphasise functional goals over radiographs.

The MIS paradigm shift is further entrenched—meta-analytic fusion equivalence and morbidity reduction affirm MIS-TLIF as default for grade I–II surgical candidates [9]. The present review extends this by incorporating late-2024 data comparing UBE-TLIF with MIS-TLIF. While UBE reduces blood loss and accelerates discharge, its protracted operative time and radiation raise ergonomic and safety considerations; maturation of surgeon experience and low-dose imaging protocols may tip the balance favorably. Importantly, both techniques preserve paraspinal musculature, mitigating postoperative atrophy that presages adjacent-segment degeneration.

Motion preservation constitutes the most disruptive advance. Pars repair's >90 % union and swift return-to-sport highlight the imperative to preserve motion in young patients—echoing historical fracture-healing principles rather than fusion dogma. For degenerative slips, early superiority data for TOPS™ mark a watershed: achieving decompression and stability without sacrificing physiologic rotation. Long-term surveillance will clarify durability and potential facet arthroplasty wear; nonetheless, the FDA's superiority label and CMS NTAP reimbursement signify institutional confidence.

High-grade lumbosacral slips remain technically challenging. Evidence synthesised here reinforces in-situ fusion as a safe, reliable workhorse, especially when spinopelvic harmony is maintained. Reduction may improve global sagittal alignment, yet the doubled incidence of transient nerve injury counsels judicious patient selection and neuromonitoring.

Adjunct technologies propel precision. Robot-guided screws minimise cortical breaches and permit percutaneous trajectories otherwise untenable; initial cost is, however, non-trivial and must be weighed against revision avoidance. AI-driven imaging—already outperforming radiologists in slip quantification—could soon stratify progression risk, personalising surveillance intervals.

Limitations of this review include inherent heterogeneity and potential publication bias toward positive outcomes. High-grade prospective data on motion-preserving implants and biologics remain sparse. Future RCTs should benchmark TOPS and dynamic stabilisers against MIS-fusion in cost-utility frameworks extending beyond two years. Additionally, registries capturing robotic and AI-enabled workflows will elucidate real-world learning curves and cost-effectiveness.

CONCLUSION

Spondylolisthesis care now embraces a spectrum from evidence-based physiotherapy to sophisticated motion-preserving implants. MIS-TLIF and UBE-TLIF deliver fusion rates equivalent to open surgery with appreciably lower morbidity, while TOPS and direct pars repair offer compelling mobility conservation for select cohorts. Emerging robotics, 3-D printing, and AI herald an era of personalised, precision spine surgery. Clinicians should adopt algorithmic pathways that match slip grade, patient goals, and comorbidity to the least disruptive yet durably effective option, whilst remaining vigilant for high-quality long-term data on novel technologies.

REFERENCES

1. Surgical and non-surgical management of spondylolisthesis. PMC, 2025.
2. Current trends in the management of degenerative lumbar spondylolisthesis. PMC, 2018.
3. Summary of Guidelines for the Treatment of Lumbar Spondylolisthesis. Neurosurg Clin N Am, 2019.
4. High-Grade Spondylolisthesis in Adults. PMC, 2020.
5. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007.
6. Ghogawala Z, Dziura J, Butler WE, et al. Laminectomy plus fusion versus laminectomy alone for lumbar spondylolisthesis. N Engl J Med. 2016.
7. Försth P, Ólafsson G, Carlsson T, et al. Decompression alone versus decompression with fusion in patients with lumbar spinal stenosis. JAMA. 2016.
8. Matz PG, Meagher RJ, Lamer T, et al. Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. J Neurosurg Spine. 2014.
9. Wu RH, Fraser JF, Härtl R, et al. Minimally invasive versus open TLIF: a meta-analysis. Eur Spine J. 2019.
10. Mobin F, Ghasemi AA, Rahimi-Movaghar V, et al. Direct pars repair for spondylolysis. Spine. 2021.