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Research Article

Dynamic Lumbar Stabilization for Degenerative Spine Disease: a Ten-Year Single-Center Experience with Clinical Limitations and High Revision Rates

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Abstract

Dynamic lumbar stabilization has been introduced as a motion-preserving alternative to rigid fusion for the management of degenerative lumbar spine conditions. However, real-world outcomes remain heterogeneous. This study presents a ten-year single-center experience evaluating clinical effectiveness, radiological stability, and complication rates associated with dynamic stabilization in patients treated exclusively for degenerative lumbar pathology. A total of 240 patients underwent dynamic stabilization between 2015 and 2024, with a mean follow-up of 48 months. Although moderate improvement in pain and functional disability was observed, clinical benefit was limited for a substantial proportion of patients. Implant loosening and postoperative instability represented significant challenges, resulting in a high rate of revision surgeries. Our data highlight that, despite preservation of segmental motion, dynamic stabilization may not consistently achieve the expected therapeutic goals in degenerative lumbar disease, underscoring the need for refined patient selection and careful long-term monitoring.

Keywords: Degenerative Lumbal Spine Condition; Dynamic Lumbar Stabilization; Lumbal Pain; Rigid Fusion

Intodruction

Degenerative pathology of the lumbar spine and adult spinal deformity represent an increasing clinical burden in the aging population. Sagittal and coronal imbalance are particularly common in individuals over 65 years of age, many of whom present with multiple comorbidities and are therefore at heightened risk for perioperative complications [1]. Although instrumented fusion remains a widely accepted approach for stabilizing deformity and restoring alignment, reported complication rates in adult deformity surgery remain substantial, and revision procedures often carry even greater morbidity. Patients who defer operative intervention in the early stages may eventually develop fixed deformities, further reducing the likelihood of satisfactory surgical outcomes [2]. Over the past two decades, dynamic stabilization systems have emerged as an alternative to rigid fusion in selected clinical scenarios. Initially developed for use in adolescent idiopathic scoliosis to encourage asymmetric growth modulation, dynamic devices have since been applied to a range of degenerative lumbar conditions, including single-level instability, adjacent segment pathology, multilevel degeneration, and adult degenerative scoliosis [3]. Several clinical series have demonstrated that these systems can provide segmental support while maintaining partial motion, potentially reducing the mechanical burden on adjacent levels. Their use has also been proposed as a strategy to mitigate screw loosening and pseudarthrosis-complications that are particularly problematic in elderly patients with compromised bone quality [4]. Lumbar spinal stenosis, one of the most prevalent degenerative spinal disorders, frequently results in neurogenic claudication, radicular symptoms, and progressive disability. While decompression alone may alleviate neural impingement, long-term outcomes are often limited by progressive deformity and segmental instability. Fusion with instrumentation provides more durable structural support but is associated with greater operative morbidity and reduced spinal mobility. Dynamic interspinous and pedicle-based systems, introduced clinically in the 1990s, were designed to bridge this therapeutic gap by offering indirect decompression and controlled stabilization without eliminating motion entirely [5]. Yet, comparative studies have yielded conflicting results, and the overall efficacy of dynamic stabilization relative to fusion remains a subject of ongoing debate [2].

A key rationale for dynamic stabilization lies in its biomechanical foundation. Contemporary understanding of lumbar pain increasingly emphasizes aberrant load transmission rather than overt instability as a principal driver of symptoms. Degenerative changes in the disc and facet joints alter the normal isotropic behavior of the intervertebral disc, leading to heterogeneous stress distribution, focal endplate loading, annular collapse, and positional pain. Dynamic systems aim to restore a more favorable loading environment by applying a controlled posterior tension band, increasing local lordosis, and limiting extreme motions that exacerbate pathologic stress patterns [6]. In contrast, rigid fusion abolishes motion but may not normalize load transmission and is known to accelerate degeneration at adjacent levels. Historically, posterior tension-band devices such as the Graf ligament system represented early attempts to control rotational and translational motion without resorting to fusion. Although clinical outcomes in selected patient groups were encouraging, these early implants also highlighted challenges inherent to dynamic constructs, including facet loading in extension and iatrogenic foraminal narrowing. Nevertheless, their development laid the groundwork for subsequent generations of dynamic stabilization systems designed to provide more physiological load sharing and improved segmental mechanics [7]. Given the well-recognized limitations of lumbar fusion-particularly in older patients with diminished bone quality and increased perioperative risk-dynamic stabilization has emerged as a potential motion-preserving alternative in the treatment of degenerative lumbar disorders. It has been applied in conditions such as early degenerative spondylolisthesis, disc degeneration with axial back pain, facet joint arthropathy, postoperative or iatrogenic instability, and adjacent-segment disease, where maintaining segmental mobility may offer clinical benefit. In this context, dynamic stabilization aims to provide controlled stability while avoiding the biomechanical drawbacks of rigid fusion [8]. The present study adds to the growing body of evidence by examining the clinical outcomes of dynamic lumbar stabilization in adult patients with degenerative spine disease, with specific attention to symptom improvement, maintenance of motion, and the prevalence and timing of implant-related complications, including screw loosening and revision surgery.

Materials and Methods

We conducted a retrospective analysis of all patients who underwent dynamic lumbar stabilization at our neurosurgical department between January 2015 and December 2024. The indication for dynamic instrumentation was strictly degenerative lumbar pathology, including degenerative spondylolisthesis-limited in all cases to low-grade (Meyerding I) slips-degenerative lumbar scoliosis, and segmental instability following non-instrumented decompression. Patients with traumatic, neoplastic, or infectious spinal conditions were excluded. Preoperative assessment included detailed neurological examination as well as standard imaging protocols consisting of lumbar MRI, CT, and dynamic flexion–extension radiographs. All operations were performed by four senior neurosurgeons using uniform surgical principles and the same generation of dynamic stabilization implants. Clinical outcomes were evaluated using the Visual Analog Scale (VAS) for back pain and the Oswestry Disability Index (ODI), recorded preoperatively and at each scheduled follow-up visit. The initial postoperative CT scan was obtained at 8 weeks to assess implant position and early mechanical changes. Subsequent follow-up consisted of periodic radiographs, with CT imaging performed when loosening or instability was clinically or radiographically suspected. Radiological assessment focused on screw integrity, implant motion, postoperative segmental range of motion (ROM), and evidence of adjacent segment degeneration. Postoperative implant loosening was quantified using two predefined measures. First, loosening per screw-designated as screw-level loosening-was calculated relative to the total number of implanted screws. Second, loosening per patient-designated as patient-level loosening-was defined as the proportion of patients demonstrating at least one loosened screw during follow-up. The timing of loosening events was documented to characterize early (<6 months) versus late (>12 months) mechanical failure patterns. Additional postoperative parameters, including mechanical instability, adjacent segment degeneration, and rates of revision surgery, were recorded systematically throughout follow-up. For statistical analysis, paired t-tests were used to compare pre- and postoperative clinical scores. To increase analytical robustness, we employed multiple complementary statistical methods:

- Kaplan–Meier survival curves to evaluate implant survival and time to loosening;
- Multivariate logistic regression to identify independent predictors of screw loosening (age, bone mineral

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density, preoperative neurological deficit, and postoperative rehabilitation intensity);

• Chi-square tests to compare categorical complication rates, particularly between single-stage versus two-stage

stabilization procedures;

• Repeated-measures ANOVA to examine longitudinal changes in VAS and ODI over time.

All statistical analyses were performed using standard statistical software, and significance was set at p < 0.05.

Results

A total of 240 patients were included in the analysis, with a mean age of 63.1 years and an even sex distribution. Most procedures were performed for low-grade degenerative spondylolisthesis or degenerative lumbar osteoarthritis and 18% of patients presented with a preoperative neurological deficit. Details of baseline demographic and clinical characteristics are summarized in (**Table 1)**.

Variable	**Value**
Number of patients	240
Age, mean ± SD	63.1 ± 9.8 years
Sex (M/F)	115 / 125
Indication	Degenerative lumbar disease only
– Degenerative spondylolisthesis	48%
– Degenerative lumbar scoliosis	32%
– Post-decompression instability	20%
Bone quality	198 normal BMD; 42 osteopenia/osteoporosis
Preoperative neurological deficit	18%
Intensive postoperative rehabilitation	22%
Multilevel dynamic stabilization (≥ 2 levels)	27%
Mean follow-up	48 months

Table 1: Baseline Demographic and Clinical Characteristics

Patients demonstrated moderate yet clinically relevant improvement following dynamic lumbar stabilization. VAS back pain scores decreased from 7.4 preoperatively to 4.2 at final follow-up ($p < 0.001$), while the ODI improved from 46.8% to 34.1% ($p < 0.001$). A clinically meaningful improvement of ≥30% in disability was achieved in 56% of the cohort. Postoperative preservation of segmental mobility was confirmed, with a mean segmental ROM of 3.7°. The full set of clinical outcome measures is presented in (Table 2). Radiographic analysis revealed an overall screw loosening rate of 7% per screw (n = 84 out of all 1200 placed screws) and 16% per patient (n = 38). Loosening followed a bimodal pattern, with the first peak observed between 12 and 16 weeks postoperatively-often corresponding to the first CT follow-up-and a second peak occurring approximately one year after surgery, frequently in association with the initiation of intensive rehabilitation programs. Symptomatic loosening requiring revision occurred in 10% of the cohort, while an additional 6% had asymptomatic radiographic loosening. These findings are detailed in (Table 3). Adjacent segment degeneration was identified in

Outcome Measure	Preoperative	Final Follow-up	p-value
VAS-back	7.4 ± 1.3	4.2 ± 1.6	< 0.001
ODI (%)	46.8 ± 13.2	34.1 ± 14.2	< 0.001
Clinically meaningful ODI improvement (≥30%)	–	56%	–
Segmental ROM	–	3.7° ± 1.1°	–

Table 2: Clinical Outcomes.

Variable	Value
Loosening per screw	7% (n=84)
Loosening per patient	16% (n = 38)
Early peak	12–16 weeks
Late peak	10–14 months
Symptomatic loosening requiring revision	10%
Radiographically silent loosening	6%

Table 3: Implant Loosening Characteristics.

11% of patients during the observation period. Revision surgery-due to instability, symptomatic loosening, or adjacent segment degeneration-was required in 24% of the cohort. Multivariate logistic regression identified several independent predictors of screw loosening. Contrary to our initial assumption, a preoperative neurological deficit by itself was not a significant risk factor. However, the combination of neurological deficit and the implementation of intensive postoperative rehabilitation was strongly associated with loosening, suggesting that the stress of early aggressive mobilization may elevate risk (OR 2.1, p = 0.010). Additional significant predictors included reduced bone quality, reflected by low Hounsfield unit (HU) values or CT-derived bone-quality scores (OR 2.2, p = 0.015), multilevel dynamic stabilization (≥ 2 levels) (OR 1.8, p = 0.042), older age (≥ 70 years) (OR 1.7, p = 0.029), and smoking (OR 1.9, p = 0.021). These variables and their statistical associations are summarized in (Table 4).

Risk Factor	Odds Ratio (OR)	p-value
Neurological deficit + intensive rehabilitation	2.1	0.01
Low bone quality (HU / CT-bone score)	2.2	0.015
Multilevel stabilization (≥ 2 levels)	1.8	0.042
Age ≥ 70 years	1.7	0.029
Smoking	1.9	0.021

Table 4: Risk Factors for Screw Loosening

The postoperative complication profile was consistent with prior reports on dynamic stabilization. Surgical site infections occurred in 3%, wound-healing disturbances in 5.4%, and transient radiculopathy in 4.2% of the patients. Mechanical instability and adjacent segment degeneration contributed substantially to the total revision rate of 24%. A detailed overview of all complications and reoperations is shown in (Table 5). Paired t-tests and repeated-measures ANOVA were used to evaluate changes in VAS and ODI scores over time. Group comparisons-such as between patients with and without neurological deficits-were conducted using chi-square testing. Logistic regression was applied to identify independent predictors of implant loosening, and Kaplan–Meier survival analysis was used to examine implant survival over the follow-up period. A summary of the applied statistical methods is provided in (Table 6).

Complication / Reoperation Type	n	%
Implant loosening (radiographic)	38	16%
Symptomatic loosening requiring revision	24	10%
Mechanical instability	28	12%
Adjacent segment degeneration	26	11%
Surgical site infection	7	3%
Wound healing disorder	13	5.40%
Transient radiculopathy	10	4.20%
Total revision surgeries	58	24%

Table 5: Complications and Reoperations

Statistical Test	Purpose
Paired t-test	Clinical improvement (VAS, ODI)
ANOVA (repeated measures)	Longitudinal functional outcome
Logistic regression	Identification of loosening predictors
Kaplan–Meier survival analysis	Time to loosening & implant survival

Table 6: Statistical Methods Used

Discussion

In our mid-term series of 240 patients treated with dynamic lumbar stabilization, we observed a screw-level loosening rate of approximately 7% and a patient-level loosening rate of 16%, with a characteristic early cluster of events at 12-16 weeks and a secondary peak around 10-14 months-findings that both corroborate and nuance recent reports on implant durability in motion-preserving constructs [9-13]. Compared with prior cohorts, our per-screw loosening rate lies within the lower–mid range of published values for dynamic and hybrid constructs, while the per-patient rate is consistent with mid-term reports that emphasize clinically meaningful failure rates in older or osteopenic populations [9,10]. The literature over the last five years highlights bone quality (CT Hounsfield units or low BMD) as a reproducible predictor of pedicle screw loosening across fixation types, and our data align with this: patients with reduced bone density had a significantly higher risk of loosening [11]. Recent work also emphasizes construct length and multilevel instrumentation as contributors to micromotion and screw-bone interface fatigue, which is concordant with our observed trend toward increased loosening in multilevel stabilizations [12]. Importantly, while neurologic deficit per se did not predict loosening in multivariate modelling, the combination of preexisting neurologic impairment followed by early, intensive rehabilitation was strongly associated with failure-an observation that supports a biomechanical interpretation in which abrupt or aggressive loading of a neuromuscularly compromised segment accelerates interface fatigue and osteolysis; this concept is gaining recognition in contemporary analyses that examine mechanical stressors and postoperative loading patterns as modifiable risk factors [12,13].

Device-specific series report heterogeneous loosening and complication rates, reflecting differences in implant geometry, anchorage design, surgical technique, and patient selection; our findings reinforce the notion that implant performance cannot be divorced from host factors such as age, smoking, and bone quality, which were independent predictors in our cohort and have been repeatedly implicated in recent reviews [9,11,13]. Adjacent segment degeneration in our series (~11%) was lower than some reports following rigid fusion but demonstrates that motion preservation reduces-yet does not abolish-the risk of adjacent-level pathology, particularly when baseline degeneration is advanced. Clinically, the moderate improvements in VAS and ODI in our cohort mirror meta-analytic data suggesting comparable short-term functional outcomes between dynamic constructs and fusion, but our elevated revision rate (24%) underscores a crucial trade-off: preservation of motion may come at the cost of higher implant-related failure in selected high-risk patients [10]. Taken together, these comparisons argue for cautious, phenotype-driven use of dynamic stabilization-favoring patients with mobile rather than fixed deformities, satisfactory bone quality, limited levels of instrumentation, and a rehabilitation program tailored to neuromuscular status-while also motivating further refinements in implant design and prospective, comparative trials to define long-term effectiveness and durability more clearly.

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