

Efficacy of an Augmented Active Control Exercise Programme on lumbar spinal mobility, trunk muscle endurance, and functional disability in lumbar disc prolapse: a randomised controlled trial

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Abstract

Background. Lumbar disc prolapse is a leading cause of pain, restricted spinal movement and functional disability in adults of working age. Conventional physiotherapy for the condition is built largely around general lumbar stretching and isolated strengthening, with limited structured progression and little emphasis on neuromuscular control. The Augmented Active Control Exercise Programme was developed as a phased, six-week protocol integrating core stabilisation, segmental control, proprioceptive retraining, unstable-surface loading and progressive angular resistance.

Objective. To compare the efficacy of the AACEP with conventional physiotherapy on lumbar spinal mobility, static and dynamic trunk muscle endurance, and functional disability in patients with lumbar disc prolapse.

Methods. This single-centre, two-arm, parallel-group randomised controlled trial was conducted in the Physiotherapy Outpatient Department of a tertiary care teaching hospital. Seventy adults aged 30–50 years with clinically diagnosed lumbar disc prolapse were randomised 1:1 to the AACEP (Group A, n = 35) or conventional physiotherapy (Group B, n = 35). Both groups trained six days per week for six weeks, 45 minutes per session, under direct supervision. Outcomes were active lumbar flexion, extension and bilateral side flexion measured with dual digital inclinometers; static endurance measured by the side bridge test; dynamic endurance measured by sit-up repetitions in 30 seconds; and disability measured by the Oswestry Disability Index. Outcomes were recorded at baseline and at the end of week six and analysed using paired and independent-samples t-tests, with Cohen's *d* and 95% confidence intervals.

Results. The groups were comparable at baseline. Within Group A, all outcomes improved significantly (all *p* < .001): flexion by 14.74°, extension by 9.77°, left side flexion by 10.31°, right side flexion by 8.74°, static endurance by 7.83 s, dynamic endurance by 2.57 repetitions, and ODI by 24.06 percentage points. Group B showed no significant change on any measure except ODI (mean change –2.86 points, *p* < .001). At six weeks, Group A was superior to Group B on every outcome (all *p* < .001). Within-group effect sizes in Group A were large for all outcomes (*d* = 2.32 to 9.45), whereas Group B effects were small and non-significant except for ODI (*d* = –0.74, 95% CI –1.111 to –0.361).

Conclusion. A six-week AACEP produced large, statistically significant and simultaneous improvements in lumbar mobility, trunk muscle endurance and functional disability that were not observed with conventional physiotherapy. The protocol is feasible within routine outpatient practice and merits evaluation in multicentre trials with longer follow-up.

Keywords: lumbar disc prolapse; exercise therapy; spinal mobility; trunk endurance; Oswestry Disability Index; randomised controlled trial.

1. Introduction

Low back pain is among the most prevalent and disabling musculoskeletal conditions worldwide, and it remains the leading cause of years lived with disability across both high- and low-income settings (Hartvigsen et al., 2018). Analyses of the Global Burden of Disease Study 2013, which examined 301 acute and chronic conditions across 188 countries between 1990 and 2013, identified low back pain as a principal contributor to the global burden of musculoskeletal disease (Collaborators & A., 2015). The economic consequences are equally substantial: comparative analyses of the socioeconomic burden of low back pain in the United States and globally document high direct healthcare expenditure alongside indirect costs from work absenteeism and lost productivity (Chang et al., 2024), a pattern first quantified in the United Kingdom, where back pain was shown to impose costs exceeding those of many other musculoskeletal conditions (Maniadakis & Gray, 2000). Because the disorder peaks during the economically productive years, its impact extends well beyond the individual patient to families, employers and health systems.

Lumbar disc prolapse — the displacement of disc material beyond the margins of the intervertebral disc space (Fardon et al., 2014) — is one of the most common structural causes of low back pain and the leading cause of lumbosacral radiculopathy. The condition most frequently affects the third to fifth decades of life and shows a male predominance, with the L4–L5 and L5–S1 segments accounting for the overwhelming majority of symptomatic herniations (Shiga, 2022)(Manchikanti, 2000). Magnetic resonance imaging studies of adults presenting with low back pain report a high prevalence of disc herniation (Azemi et al., 2022), and systematic review evidence confirms that the incidence of disc herniation with radiculopathy is substantial and rises steadily with age (Hincapié et al., 2024). Importantly, degenerative changes are also frequently observed in asymptomatic individuals, underlining the need for clinical correlation rather than imaging findings alone in diagnosis (Kanayama et al., 2009). The natural history of the condition is variable: many patients improve with conservative management, and spontaneous resorption of herniated material occurs in a meaningful proportion of cases, mediated in part by an inflammatory response (Cunha et al., 2018)(Zeng et al., 2023). Accordingly, most clinical guidelines reserve surgery for progressive neurological deficit or failure of conservative care, and rehabilitation remains the mainstay of first-line management (Peul et al., 2007)(Gugliotta et al., 2016).

The clinical and functional consequences of disc prolapse are not confined to the compressed nerve root. Imaging studies consistently demonstrate reduced cross-sectional area and increased fatty infiltration of the lumbar multifidus in patients with disc prolapse, and the severity of these changes correlates with the grade of disc degeneration (Faur et al., 2019). Histochemical studies of the multifidus in disc herniation report selective atrophy of type I and type II fibres on the symptomatic side, consistent with denervation and pain-related inhibition (Zhao et al., 2000)(Yoshihara et al., 2001), and these changes persist years after surgical treatment (Rantanen et al., 1993). Asymmetric degeneration of the multifidus and erector spinae has likewise been demonstrated in patients with disc herniation with and without root compression (Yazıcı & Yerlikaya, 2022). Functionally, these alterations compromise the active subsystem of spinal stability, which, within Panjabi's model, operates alongside the passive structures and the neural control system to maintain segmental equilibrium (Panjabi, 1992). Deficits in the active and neural subsystems are clinically important because they restrict movement, reduce the capacity to sustain postural tasks, and leave patients vulnerable to recurrence — which is precisely the profile captured by restricted lumbar range of motion, impaired trunk endurance and elevated disability.

Range of motion is a widely used indicator of spinal function. People with back pain display altered lumbo-pelvic kinematics compared with pain-free individuals (Laird et al., 2014), and restricted lumbar mobility is one of the most consistent findings in patients with disc pathology. Trunk muscle endurance is a second, arguably more functionally relevant, domain. Reduced endurance of the lumbar extensors and lateral trunk musculature is repeatedly documented in low back pain populations, and systematic review with meta-analysis shows that exercise interventions can improve lumbar extensor strength, endurance and electromyographic activation in individuals with spinal pain (Clael et al., 2021). Disability, most commonly quantified with the Oswestry Disability Index — a validated, self-administered instrument covering ten domains of daily living (Vianin, 2008) — represents the cumulative functional expression of these impairments and is the outcome that matters most to patients. Contemporary frameworks for assessing chronic low back pain accordingly recommend that recovery be evaluated across multiple domains rather than by pain intensity alone (Tagliaferri et al., 2019).

Exercise therapy is the cornerstone of conservative management, and structured programmes consistently improve pain, mobility, strength and endurance in this population (Wang et al., 2024). Randomised trials of trunk-focused exercise demonstrate improvements in pain, disability, quality of life and trunk physical fitness, with specific benefits for mobility and endurance (Prat-Luri et al., 2023). Trials of stabilisation and motor control exercise in chronic lumbar disc herniation report gains in pain, mobility and trunk endurance (Ameri et al., 2025), and core stabilisation has been compared directly with Pilates for pain intensity, lumbar range of motion and daily activity performance (Chughtai et al., 2025). Core stabilisation added to conventional treatment has also been shown to increase back muscle endurance in disc herniation (Jamil et al., 2023), and meta-regression evidence indicates a dose–response relationship between the volume of stabilisation exercise and clinical improvement in chronic low back pain (Mueller & Niederer, 2020). Core stabilisation exercise outperforms isolated strengthening for proprioception, balance, muscle thickness and

pain-related outcomes (Hlaing et al., 2021), and stabilisation training improves lumbar movement sense (Boucher et al., 2016). Systematic reviews of proprioceptive exercise in chronic neck and low back pain reach broadly similar conclusions (McCaskey et al., 2014), as do reviews of manual therapy combined with exercise across stages of non-specific low back pain (Hidalgo et al., 2013).

Two gaps nevertheless remain. First, most conventional programmes for disc prolapse are constructed around general lumbar stretching and isolated strengthening, without structured layering or resistance progression; the result is a treatment stimulus that is frequently insufficient to challenge the neuromuscular system in the way that contemporary models of spinal rehabilitation recommend (Mueller & Niederer, 2020)(Wang et al., 2024). Second, trials in this population typically report single-domain outcomes — most often pain or disability — so the extent to which an intervention improves mobility and endurance simultaneously, and whether those gains are mirrored by corresponding changes in disability, is often unclear (Prat-Luri et al., 2023)(Tagliaferri et al., 2019).

The Augmented Active Control Exercise Programme was developed by our group to address both gaps. It is a phased, six-week protocol that integrates core stabilisation, segmental control, neuromuscular re-education, proprioceptive and unstable-surface training, and progressive angular resistance, with exercises layered weekly according to individual tolerance and performance (Indian Copyright Registration No. L-148816/2024). The protocol was pilot-tested before implementation in the present trial.

The aim of this randomised controlled trial was therefore to evaluate the effects of a six-week AACEP, compared with conventional physiotherapy, on lumbar spinal mobility, static and dynamic trunk muscle endurance, and functional disability in patients with lumbar disc prolapse. We hypothesised that the AACEP would produce significantly greater improvements than conventional physiotherapy across all of these domains.

2. Materials and methods

2.1 Study design, setting and reporting

The study employed a quantitative, experimental design — a pretest–posttest, parallel-group randomised controlled trial — to evaluate the efficacy of the AACEP in individuals with lumbar disc prolapse. The trial was conducted in the Physiotherapy Outpatient Department of Shree Guru Gobind Singh Tricentenary Medical College Hospital and Research Institute, Gurugram, Haryana, India. The study was designed, conducted and reported in accordance with the Consolidated Standards of Reporting Trials 2010 statement (Group et al., 2010), and reporting of outcome definitions followed the CONSORT-Outcomes 2022 extension (Tugwell et al., 2024).

2.2 Ethics approval and trial registration

The study protocol was approved by the Institutional Ethical Committee of SGT University, Gurugram (IEC No. SGTU/FPHY/2023/329), and was conducted in accordance with the Declaration of Helsinki. All participants received a detailed explanation of the study procedures in their local language before enrolment and provided written informed consent. The trial was prospectively registered in the Clinical Trials Registry – India (CTRI/2024/06/068785).

2.3 Participants

Participants were recruited from patients attending the Orthopaedic and Physiotherapy outpatient departments of the host institution. Individuals were eligible if they were aged 30–50 years (male or female); had low back pain with or without radiculopathy; had disc prolapse at any lumbar level (L1–S1); had a clinical diagnosis of lumbar disc prolapse confirmed by an orthopaedic surgeon on the basis of physical examination, symptom history and clinical signs, without mandatory imaging; reported symptom duration exceeding three months; were able to understand and follow verbal and written instructions; were willing to attend supervised physiotherapy sessions for six weeks; had stable cardiovascular status; and were willing to provide blood samples for biomarker analysis.

Individuals were excluded if they had tumour, infection or tuberculosis; any traumatic condition of the pelvis or lower limb; an uncontrolled mood disorder; a history of lumbar spine surgery or invasive spinal procedures; current use of corticosteroids or immunosuppressive medications; use of analgesic drugs in the

preceding week likely to affect pain reporting; a progressive motor neurological deficit, bladder or bowel involvement, or marked difficulty in walking; or a previous inner ear infection or vestibular disorder with unresolved balance disturbance.

2.4 Sample size

An a priori power analysis was performed using G*Power software (version 3.1.9.7) (Kang, 2021)(Faul et al., 2007)(Faul et al., 2009). Assuming a large effect size (Cohen's $d = 0.8$), a significance level of 5% ($\alpha = 0.05$) and a statistical power of 95% ($1 - \beta = 0.95$), a total of 70 participants (35 per group) was required to detect a meaningful difference between two independent means. The expected effect size was estimated from previously published randomised controlled trials of exercise-based rehabilitation in lumbar disc prolapse (Mueller & Niederer, 2020)(Ameri et al., 2025).

2.5 Randomisation, allocation concealment and blinding

Eligible participants were recruited using convenience sampling. Of 105 individuals assessed for eligibility, 28 were excluded at screening and 78 were randomly allocated in a 1:1 ratio to either Group A (AACEP, $n = 39$) or Group B (conventional physiotherapy, $n = 39$) using a computer-generated randomisation sequence. Allocation concealment was ensured using sequentially numbered, sealed, opaque envelopes, opened only after participant enrolment. Eight participants withdrew after randomisation (three in Group A and four in Group B), leaving 70 participants (35 per group) who completed the full intervention and both assessment points and were included in the analysis. Participant retention was supported by regular telephone contact, standardised written instructions and directly supervised sessions, consistent with evidence on effective retention strategies in randomised trials (Gillies et al., 2021)(Toerien et al., 2009).

The study employed a single-blind design. Participants were blinded to group allocation and were not informed which intervention constituted the experimental treatment. Owing to the nature of the physiotherapy interventions, blinding of the treating therapist was not feasible, and all outcome assessments were performed by the principal investigator.

2.6 Interventions

All sessions in both groups were supervised and took place six days per week for six weeks, each lasting 45 minutes. Each exercise was performed for one set of 10 repetitions with a 30-second rest interval between exercises, within a pain-free range of motion, avoiding any position that exacerbated symptoms.

Experimental group. Participants received the AACEP, a structured, progressive rehabilitation protocol developed by the researcher (Indian Copyright Registration No. L-148816/2024), integrating core stabilisation, segmental control and neuromuscular re-education, and targeting abdominal, hip and spinal musculature. The programme was delivered in progressive phases. Foundational exercises introduced during weeks 0–2 — abdominal bracing, lying side kicks, crook back press, side hunches, supine hip abduction with knee flexion, the bridge, and supine twirls — were continued throughout the intervention to reinforce neuromuscular activation, motor learning and trunk endurance. Additional exercises were introduced sequentially in later phases to progressively increase neuromuscular and functional demand: tripod leg circles; single knee-to-chest isometric abdominal exercise and its advanced variant; single knee slide-ups; fire hydrants; extended slopes; hump and hollow poses; the hundred; half-kneeling twist; medicine ball slashes (0.5 kg); quadripod knee lift; Thera twirls with a yellow Theraband; standing twist on a Bosu ball (0.5 kg medicine ball); knee lunge stretch; resisted angular twist at 45°, 90° and 130° against a yellow Theraband; tripod leg swing; forearm plank; trunk side rotation, back extension and trunk side flexion on a Bosu ball; and the mould pattern. Where the protocol specified a 0.5 kg medicine ball, an equivalent 0.5 kg dumbbell was substituted, as a 0.5 kg medicine ball was not commercially available; the external resistance, movement pattern, exercise sequence and progression remained otherwise unchanged. Exercise intensity and complexity were progressed weekly according to individual tolerance and performance.

Control group. Participants received a conventional physiotherapy regimen reflecting routine clinical practice for lumbar disc prolapse, emphasising general lumbar muscle stretching and strengthening without supplementary neuromuscular or proprioceptive components. The programme comprised spinal extension exercises (simple back extension, bird dog, prone press-ups) and spinal flexion exercises (knee-to-chest stretch, lower back rotational stretch, pelvic tilt, bridge, cat and camel stretch, lumbar crunches). Exercises were performed at a consistent intensity throughout the intervention, without structured layering or

resistance progression, and were matched to the experimental group for frequency (six days per week), session duration (45 minutes) and treatment period (six weeks).

2.7 Outcome measures

All outcomes were recorded at baseline (day 1 of the intervention) and again at completion of the six-week programme, for both groups.

Lumbar range of motion. Active lumbar flexion, extension and left and right side flexion were measured in degrees using two synchronised digital inclinometers (LABART™) positioned over the T12 vertebra and the S1 vertebra (midline between the posterior superior iliac spines), following standardised dual-inclinometer procedures recommended by the American Medical Association. Each movement was performed three times and the mean value recorded; the range of motion for each movement was calculated as the reading at T12 minus the reading at S1. All measurements were performed by the same examiner to ensure intra-rater consistency.

Static trunk muscle endurance. Static endurance of the lateral trunk musculature was assessed with the side bridge test. Participants were positioned in side-lying with legs fully extended, the supporting elbow flexed to 90°, and the hips elevated to maintain a straight body line supported on the forearm and feet. The test was terminated when the participant could no longer sustain the posture, and the holding time was recorded in seconds. The test demonstrates excellent intra-tester (ICC = 0.89) and inter-tester (ICC = 0.88) reliability.

Dynamic trunk muscle endurance. Dynamic endurance of the trunk flexors was assessed by asking participants to perform repeated trunk flexion movements with knees flexed and feet stabilised; the number of sit-up repetitions completed within a 30-second interval was recorded. The test has high test-retest reliability ($r = 0.98$) and inter-tester reliability ($r = 0.76$).

Functional disability. Disability was assessed using the Oswestry Disability Index, a validated, self-administered questionnaire comprising 10 sections, each scored 0–5, covering pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life and travelling (Vianin, 2008). The total score is expressed as a percentage (0–100%) using the standard scoring formula, with higher scores indicating greater disability; scores of 0–20% represent minimal disability, 21–40% moderate disability, 41–60% severe disability, 61–80% crippling disability, and 81–100% bed-bound status.

2.8 Statistical analysis

Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics for Windows (version 32.0, IBM Corp., Armonk, NY, USA). Data were checked for completeness, consistency, coding errors and missing values before analysis (Bell et al., 2014). Descriptive statistics are presented as mean $\pm$ standard deviation for continuous variables and as frequencies and percentages for categorical variables. Normality of all outcome variables was assessed using the Shapiro–Wilk test; data were normally distributed ($p > 0.05$), permitting parametric analysis.

Baseline demographic characteristics and baseline outcome values were compared between groups using independent-samples t-tests. These comparisons are presented for descriptive purposes only and were not used to establish group equivalence or to guide covariate selection, in line with current methodological guidance on baseline testing in randomised trials (Boer et al., 2015)(Ahn et al., 2018)(Gruijters, 2020). Within-group comparisons between baseline and post-intervention values were performed using paired-samples t-tests, separately for each group. Between-group comparisons of post-intervention values were performed using independent-samples t-tests. Standardised within-group effect sizes (Cohen's $d_z = t/\sqrt{n}$) with 95% confidence intervals were calculated and interpreted according to conventional thresholds (0.2 small, 0.5 moderate, 0.8 large). All statistical tests were two-tailed, and statistical significance was set at $p < 0.05$.

3. Results

3.1 Participant flow and baseline characteristics

Of 105 individuals assessed for eligibility, 28 were excluded at screening and 78 were randomised (Group A, $n = 39$; Group B, $n = 39$). Seven participants withdrew after randomisation (three in Group A, four in Group B), leaving 70 participants (35 per group) who completed the intervention and both assessment points.

Analysis was therefore based on 70 participants.

The two groups were comparable at baseline on all demographic variables. Mean age was 42.3 ± 4.31 years in Group A and 42.2 ± 3.98 years in Group B, and mean BMI was 24.84 ± 1.50 versus 25.09 ± 1.49 kg/m², respectively. The sex distribution was similar (Group A: 14 females, 21 males; Group B: 12 females, 23 males). Baseline outcome values did not differ significantly between groups.

Table 1. Baseline demographic and outcome characteristics of the two groups.

Variable	Group A (n = 35)	Group B (n = 35)	p
Age (years)	42.3 ± 4.31	42.2 ± 3.98	NS
Height (cm)	167.69 ± 6.1	167.94 ± 6.58	NS
Weight (kg)	70.14 ± 8.54	71.08 ± 8.86	NS
BMI (kg/m ²)	24.84 ± 1.50	25.09 ± 1.49	NS
Sex (F/M)	14/21	12/23	NS
Lumbar flexion (°)	48.54 ± 4.90	47.29 ± 4.47	0.266 ^{NS}
Lumbar extension (°)	19.74 ± 2.47	20.17 ± 2.43	0.467 ^{NS}
Left side flexion (°)	18.46 ± 1.92	19.40 ± 3.30	0.150 ^{NS}
Right side flexion (°)	18.34 ± 1.70	17.66 ± 1.89	0.115 ^{NS}
Static endurance (s)	7.94 ± 0.91	7.66 ± 1.00	0.214 ^{NS}
Dynamic endurance (reps/30 s)	7.00 ± 0.77	6.77 ± 0.94	0.270 ^{NS}
ODI (%)	47.46 ± 3.43	46.80 ± 3.43	0.426 ^{NS}

Values are expressed as mean $\pm$ SD. Group A = Augmented Active Control Exercise Program (n = 35); Group B = conventional physiotherapy (n = 35). ODI = Oswestry Disability Index; Between-group comparisons at baseline were performed using the independent samples t-test. *p $\leq$ 0.05 = significant; **p $\leq$ 0.001 = highly significant; NS = not significant.

3.2 Within-group changes

In Group A, paired-samples t-tests (df = 34) demonstrated highly significant improvements from baseline to six weeks on all seven outcomes (all p < .001; Table 2). Lumbar flexion increased by 14.74° , extension by 9.77° , left side flexion by 10.31° and right side flexion by 8.74° . Static endurance increased by 7.83 s — approximately a doubling of the baseline value — and dynamic endurance rose by 2.57 repetitions. ODI decreased by 24.06 percentage points, from $47.46 \pm 3.43\%$ to $23.40 \pm 2.17\%$, moving the group mean from the severe disability band to the lower boundary of the moderate band.

Group B remained essentially stable over the six weeks. Apart from a small but statistically significant reduction in ODI ($46.80 \pm 3.43\%$ to $43.94 \pm 4.52\%$; mean change -2.86 points, t = 4.380, p < .001), no outcome changed significantly (all p > 0.05; Table 2). In particular, lumbar kinematics and both endurance measures were unchanged.

Table 2. Within-group pre- to post-intervention changes (paired-samples t-tests, df = 34).

Outcome	Group A Pre	Group A Post	Δ (A)	p (A)	Group B Pre	Group B Post	Δ (B)	p (B)
Flexion (°)	48.54 ± 4.90	63.29 ± 5.42	+14.74	<.001**	47.29 ± 4.47	47.66 ± 4.81	+0.37	0.10 ^{NS}
Extension (°)	19.74 ± 2.47	29.51 ± 3.32	+9.77	<.001**	20.17 ± 2.43	20.31 ± 2.54	+0.14	0.16 ^{NS}
Left side flexion (°)	18.46 ± 1.92	28.77 ± 3.32	+10.31	<.001**	19.40 ± 3.30	19.74 ± 2.70	+0.34	0.14 ^{NS}
Right side flexion (°)	$18.34 \pm$	$27.09 \pm$	+8.74	<.001**	$17.66 \pm$	$17.80 \pm$	+0.14	0.23 ^{NS}

	1.70	3.05			1.89	1.86		
Static endurance (s)	7.94 ± 0.91	15.77 ± 3.38	+7.83	<.001**	7.66 ± 1.00	7.86 ± 1.00	+0.20	0.12 ^{NS}
Dynamic endurance (reps/30 s)	7.00 ± 0.77	9.57 ± 0.50	+2.57	<.001**	6.77 ± 0.94	7.00 ± 1.33	+0.23	0.18 ^{NS}
ODI (%)	47.46 ± 3.43	23.40 ± 2.17	-24.06	<.001**	46.80 ± 3.43	43.94 ± 4.52	-2.86	<.001**

Values are mean ± SD; Δ = post – pre difference. Paired-samples t-tests, two-tailed, df = 34. For ODI, negative Δ = improvement. *p ≤ 0.05 = significant; **p ≤ 0.001 = highly significant; NS = not significant.

3.3 Between-group comparison at six weeks

Independent-samples t-tests (df = 68) revealed highly significant differences between the groups on every outcome at the end of the intervention (all p < .001; Table 3). Group A demonstrated greater lumbar flexion, extension and bilateral side flexion, markedly greater static and dynamic endurance, and lower ODI scores than Group B. Static endurance in Group A was approximately double that of Group B (15.77 ± 3.38 s vs 7.86 ± 1.00 s), and ODI was more than 20 percentage points lower (23.40 ± 2.17% vs 43.94 ± 4.52%), corresponding to moderate versus severe disability on the standard categorical classification.

Table 3. Post-intervention (week 6) between-group comparison (independent-samples t-tests, df = 68).

Outcome	Group A (n = 35)	Group B (n = 35)	p
Flexion (°)	63.29 ± 5.42	47.66 ± 4.81	<.001**
Extension (°)	29.51 ± 3.32	20.31 ± 2.54	<.001**
Left side flexion (°)	28.77 ± 3.32	19.74 ± 2.70	<.001**
Right side flexion (°)	27.09 ± 3.05	17.80 ± 1.86	<.001**
Static endurance (s)	15.77 ± 3.38	7.86 ± 1.00	<.001**
Dynamic endurance (reps/30 s)	9.57 ± 0.50	7.00 ± 1.33	<.001**
ODI (%)	23.40 ± 2.17	43.94 ± 4.52	<.001**

Values are post-intervention means ± SD; independent-samples t-tests, two-tailed, df = 68. ODI = Oswestry Disability Index. *p ≤ 0.05 = significant; **p ≤ 0.001 = highly significant; NS = not significant.

3.4 Effect sizes

Cohen's dz for paired differences confirmed large effects for every outcome in Group A, with all 95% confidence intervals excluding zero. The largest effects were observed for lumbar flexion (dz = 9.45) and ODI (dz = -6.35); the smallest, static endurance (dz = 2.32), still substantially exceeded the conventional large-effect benchmark of 0.8. In Group B, effect sizes were small for all outcomes except ODI, which showed a moderate effect (dz = -0.74) consistent with the small significant reduction in disability in that group. Effect sizes are reported as paired-difference indices; for ODI, negative values denote improvement.

Table 4. Within-group effect sizes (Cohen's dz = t/√n) with 95% confidence intervals.

Outcome	Group A dz (95% CI)	Group B dz (95% CI)
Flexion (°)	+9.45 (+7.18 to +11.72)	+0.279 (-0.0615 to +0.615)
Extension (°)	+5.04 (+3.79 to +6.28)	+0.238 (-0.100 to +0.572)
Left side flexion (°)	+6.44 (+4.88 to +8.01)	+0.250 (-0.088 to +0.585)
Right side flexion (°)	+4.05 (+3.03 to +5.06)	+0.206 (-0.130 to +0.540)
Static endurance (s)	+2.32 (+1.68 to +2.97)	+0.263 (-0.076 to +0.599)
Dynamic endurance (reps/30 s)	+5.14 (+3.87 to +6.41)	+0.228 (-0.109 to +0.562)

ODI (%)	-6.35 (-7.89 to -4.80)	-0.74 (-1.111 to -0.361)
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Values are Cohen's d_z (95% CI) from paired-samples t -tests ($df = 34$); $d_z = t/\sqrt{n}$. CI excluding zero = significant change; for ODI, negative d_z = improvement. Effect size: <0.5 small, $0.5-0.8$ medium, >0.8 large. In summary, six weeks of the AACEP produced large, simultaneous improvements across biomechanical (lumbar kinematics), neuromuscular (static and dynamic trunk endurance) and functional (disability) domains, whereas conventional physiotherapy produced no significant change on any outcome apart from a small reduction in disability.

4. Discussion

The present randomised controlled trial evaluated the efficacy of a six-week AACEP against conventional physiotherapy in 70 individuals with lumbar disc prolapse, with outcomes spanning lumbar spinal mobility, static and dynamic trunk endurance, and functional disability. The principal finding was that the experimental group achieved highly significant improvements in every outcome domain, whereas the control group remained essentially unchanged apart from a small reduction in disability. Critically, the effects of the intervention were not confined to a single aspect of recovery but extended simultaneously across movement, muscular endurance and function. This pattern supports the concept that rehabilitation of lumbar disc prolapse should address the integrated spinal stabilising system rather than isolated impairments.

The groups were comparable at baseline on all demographic variables and all outcome measures, and post-intervention differences are therefore unlikely to reflect pre-existing disparities. It should be noted that baseline comparability in randomised trials is a consequence of randomisation itself, and baseline significance testing is not a valid method for demonstrating that randomisation succeeded (Boer et al., 2015)(Ahn et al., 2018)(Gruijters, 2020); the baseline data are presented here to characterise the sample rather than to establish equivalence. The demographic profile of the sample is consistent with the documented epidemiology of lumbar disc prolapse: the mean age of approximately 42 years falls within the peak-incidence window of 30–50 years, and the male preponderance (44 males, 26 females) is consistent with the influence of cumulative mechanical loading and occupational exposure described in the literature (Shiga, 2022)(Hincapié et al., 2024)(VN et al., 2021).

4.1 Lumbar spinal mobility

Six weeks of the AACEP produced large gains in lumbar mobility: flexion increased by 14.74° , extension by 9.77° , and bilateral side flexion by approximately $9-10^\circ$, all with large paired-difference effect sizes ($d_z = 4.05$ to 6.44), while the control group showed negligible change in every movement direction (e.g., flexion $+0.37^\circ$, $p = 0.10$). These findings align with a substantial body of evidence demonstrating that structured exercise improves lumbar range of motion in disc herniation. Randomised comparisons of stabilisation-based programmes have reported meaningful gains in lumbar mobility alongside improvements in pain and disability (Ameri et al., 2025)(Chughtai et al., 2025), and systematic review evidence indicates that exercise programmes of six to twelve weeks consistently improve spinal mobility, pain, physical function and quality of life in lumbar disc herniation (Wang et al., 2024). Trunk-focused exercise has similarly been shown to improve mobility, disability and quality of life in people with spinal pain (Prat-Luri et al., 2023).

Several interacting mechanisms plausibly underlie the restoration of mobility. Restricted movement in disc prolapse arises from pain, reflex muscle guarding, reduced peri-spinal tissue extensibility and disrupted neuromuscular control. Progressive exercise reverses these maladaptive responses by restoring coordinated muscle activation, enhancing segmental stability, and gradually exposing pain-sensitive structures to controlled loading. The concurrent improvements in trunk endurance in the experimental group support this interpretation, since efficient spinal movement depends on continuous interaction between the active muscular system and the sensorimotor control mechanisms that regulate it (Panjabi, 1992)(Laird et al., 2014). The multidimensional design of the AACEP — progressive core activation, dynamic stabilisation on unstable surfaces, resisted angular twisting and multi-planar movement control — likely accounts for the magnitude of the gains, consistent with evidence that interventions incorporating neuromuscular control and coordination training yield superior movement-quality outcomes in spinal

disorders (Hlaing et al., 2021)(Boucher et al., 2016)(McCaskey et al., 2014).

4.2 Static trunk muscle endurance

Static endurance, assessed with the side bridge test, nearly doubled in the experimental group, from 7.94 ± 0.91 s to 15.77 ± 3.38 s ($d_z = +2.32$), whereas it did not change significantly in the control group (7.66 ± 1.00 s to 7.86 ± 1.00 s, $p = 0.12$). Reduced trunk endurance is consistently observed in low back pain and is identified as a risk factor for the development and persistence of symptoms, since fatiguing stabilisers lose the capacity to maintain segmental stiffness and resist shear forces (Clael et al., 2021). The present gains align with trial evidence that core stabilisation added to conventional treatment significantly increases back muscle endurance in disc herniation (Jamil et al., 2023), and with meta-analytic evidence that exercise improves lumbar extensor strength, endurance and electrical activity in non-specific low back pain (Clael et al., 2021). Meta-regression evidence further indicates that the dose of stabilisation exercise is related to the magnitude of improvement, supporting the value of structured progression (Mueller & Niederer, 2020). The AACEP retained foundational isometric control work throughout while progressively adding dynamic and unstable-surface challenges, providing a graduated stimulus consistent with contemporary recommendations that rehabilitation progress from motor control to functional strengthening (Jamil et al., 2023)(Prat-Luri et al., 2023). Given that most daily and occupational activities require prolonged low-intensity activation of the stabilising musculature rather than maximal force, the restoration of static endurance has direct functional relevance for maintaining spinal alignment during sitting, standing, lifting and repetitive tasks.

4.3 Dynamic trunk muscle endurance

Dynamic endurance, assessed as sit-up repetitions in 30 seconds, rose from 7.00 ± 0.77 to 9.57 ± 0.50 repetitions in the experimental group ($d_z = +5.14$) and was unchanged in the control group (6.77 ± 0.94 to 7.00 ± 1.33 , $p = 0.18$). Dynamic endurance reflects the capacity to sustain repeated trunk movement — the demand profile of lifting, bending and transitional tasks — and is typically reduced in patients with chronic low back pain, in whom earlier fatigue leads to compensatory recruitment of superficial muscles and increased spinal loading. Trials in chronic lumbar disc herniation have reported improvements in trunk endurance following stabilisation-based programmes (Ameri et al., 2025), and reviews of trunk-focused exercise document gains in trunk physical fitness alongside reduced disability (Prat-Luri et al., 2023). The magnitude of the effect observed here is best explained by the layering of the protocol: the progressive addition of resisted angular twists at 45°, 90° and 130°, medicine ball work, Bosu-ball trunk rotation and the mould pattern imposed repeated multi-planar dynamic demand that conventional flexion and extension exercises do not.

4.4 Functional disability

Functional disability showed the most clinically striking improvement. The experimental group's ODI fell by 24.06 percentage points, from $47.46 \pm 3.43\%$ (severe disability) to $23.40 \pm 2.17\%$ (lower boundary of the moderate band), with the largest effect size of any outcome other than flexion ($d_z = -6.35$), whereas the control group declined by only 2.86 points despite a statistically significant within-group change. Interpreted against the standard ODI classification, in which 0–20% denotes minimal, 21–40% moderate and 41–60% severe disability, this represents a transition across an entire disability category and is likely to reflect a substantial change in the ability to perform activities of daily living (Vianin, 2008).

These findings are consistent with the broader rehabilitation literature. Core stabilisation exercise has produced greater disability reductions than conventional treatment in disc herniation (Jamil et al., 2023), and core stabilisation has been shown to be more effective than isolated modalities for reducing disability in this population. Systematic review evidence confirms that structured exercise combining stabilisation, motor control and progressive loading consistently reduces disability in lumbar disc herniation (Wang et al., 2024)(Prat-Luri et al., 2023). Contemporary frameworks for assessing chronic low back pain emphasise that recovery should be judged across multiple domains rather than by a single measure (Tagliaferri et al., 2019), and the present results support that position: the reduction in disability tracked the concurrent gains in mobility and endurance rather than occurring in isolation.

The magnitude of the reduction observed here is plausibly explained by the cumulative improvements in mobility and endurance. By addressing these impairments simultaneously, the AACEP appears to have produced a synergistic rather than additive improvement in functional capacity. The modest control-group

reduction is consistent with the finding that any structured supervised exercise confers some functional benefit (Wang et al., 2024)(Gugliotta et al., 2016); however, the effect in the experimental group was several times larger, indicating the incremental value of the augmented protocol.

4.5 Integration across domains

Within contemporary models of spinal stability — passive structures, active musculature and neural control functioning as an integrated system (Panjabi, 1992) — the present findings indicate that the AACEP addressed all three subsystems concurrently. Endurance gains reflect restoration of the active subsystem; mobility gains reflect its functional integration with neural control; and the reduction in disability represents the cumulative clinical expression of these interacting adaptations. This interdependence is well illustrated by the documented relationship between muscular fatigue and movement quality: fatiguing stabilisers compromise the maintenance of segmental stiffness and can degrade the precision of spinal control (Clael et al., 2021)(Panjabi, 1992). Conversely, endurance-trained musculature preserves movement quality during sustained activity, and the mobility gains observed here are consistent with that mechanism. It is also relevant that the control group, which received comparable supervision, frequency and duration but no structured progression or unstable-surface loading, showed no improvement in mobility or endurance — a pattern indicating that the observed benefits were attributable to the content and progression of the programme rather than to supervision, attention or the passage of time. Methodological guidance on the interpretation of trial findings cautions against attributing outcomes to non-specific factors without such a comparator, and the matched design of the present trial addresses that concern directly (Shang et al., 2025)(Roode et al., 2024).

4.6 Strengths and limitations

The principal strengths of this trial are its randomised, parallel-group design; the use of a matched active comparator that controlled for supervision, session frequency and duration; the a priori power calculation; the use of objective, instrument-based measurement of mobility and endurance alongside a validated patient-reported disability instrument (Vianin, 2008); and the reporting of effect sizes with confidence intervals rather than reliance on p-values alone (Tugwell et al., 2024). The use of a genuine active control condition is a particular strength, since it isolates the incremental effect of the augmented protocol over routine care rather than comparing exercise with no treatment.

The study was conducted at a single centre with a six-week intervention and no long-term follow-up, so the durability of the observed gains remains to be established. The sample comprised adults aged 30–50 years recruited by convenience sampling, which may limit generalisability to older adults, postoperative patients or those with severe neurological deficits. The study employed a single-blind design: participants were blinded to allocation, but blinding of the treating therapist was not feasible and all outcome assessments were performed by the researcher.

4.7 Clinical implications and future directions

The findings suggest that rehabilitation programmes for lumbar disc prolapse should incorporate explicit progressive and dynamic control components — layered core activation, unstable-surface training and multi-planar resistance — rather than focusing exclusively on general stretching and isolated strengthening (Prat-Luri et al., 2023)(Mueller & Niederer, 2020). The emphasis of the protocol on static and dynamic endurance is supported by meta-analytic evidence that exercise improves lumbar extensor strength, endurance and activation in individuals with spinal pain (Clael et al., 2021), and by evidence that stabilisation exercise confers dose-dependent benefit (Mueller & Niederer, 2020). Disability should be monitored routinely using the ODI, and recovery conceptualised and evaluated across multiple outcome domains rather than a single measure (Tagliaferri et al., 2019). Because the programme uses equipment readily available in physiotherapy departments and progresses according to individual tolerance, it is feasible for delivery in hospital, academic and community-based rehabilitation settings. Multicentre trials with larger samples, longer follow-up, assessor blinding and imaging-based assessment are warranted to confirm the durability of these benefits and to characterise the mechanisms underlying exercise-induced improvement in this population (Oosterhuis et al., 2014)(Steffens et al., 2016).

5. Conclusion

Within the limits of this randomised controlled trial, a six-week Augmented Active Control Exercise Programme was superior to conventional physiotherapy in individuals with lumbar disc prolapse, producing large and statistically significant improvements in lumbar spinal mobility, static and dynamic trunk muscle endurance, and functional disability, with the ODI falling by 24.06 percentage points from severe to moderate disability. The control group showed no meaningful change on any outcome apart from a small reduction in disability. The convergence of large effect sizes across biomechanical, neuromuscular and functional domains indicates that the AACEP acted on the integrated spinal stabilising system rather than on isolated impairments. Given its feasibility within a routine outpatient setting using readily available equipment, the AACEP represents a clinically practicable conservative rehabilitation strategy for lumbar disc prolapse; multicentre trials with larger samples and longer follow-up are warranted to confirm the durability of these benefits.

References

1. Ahn, E. J., Kim, J., Kim, T. K., Park, J. H., Lee, D. K., Lee, S., In, J., & Kang, H. (2018). Assessment of P values for demographic data in randomized controlled trials. *Korean Journal of Anesthesiology*, 72(2), 130–134. <https://doi.org/10.4097/kja.d.18.00333>
2. Ameri, B., Fatahi, A., Abadi, R. N., & Molavian, R. (2025). Dynamic Neuromuscular Stabilization Exercise and Chronic Lumbar Disc Herniation: Effects on Pain, Mobility, and Trunk Endurance—A Randomized Controlled Trial. *Health Science Reports*, 8(12). <https://doi.org/10.1002/hsr2.71611>
3. Azemi, E. S., Kola, I., Kola, S., & Tanka, M. (2022). Prevalence of Lumbar Disk Herniation in Adult Patients with Low Back Pain Based in Magnetic Resonance Imaging Diagnosis. *Open Access Macedonian Journal of Medical Sciences*, 10, 1720–1725. <https://doi.org/10.3889/oamjms.2022.8768>
4. Bell, M. L., Fiero, M. H., Horton, N. J., & Hsu, C. (2014). Handling missing data in RCTs; a review of the top medical journals. *BMC Medical Research Methodology*, 14(1), 118. <https://doi.org/10.1186/1471-2288-14-118>
5. Boer, M. R. de, Waterlander, W., Kuijper, L. D. J., Steenhuis, I. H., & Twisk, J. W. R. (2015). Testing for baseline differences in randomized controlled trials: an unhealthy research behavior that is hard to eradicate. *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), 4. <https://doi.org/10.1186/s12966-015-0162-z>
6. Boucher, J.-A., Preuss, R., Henry, S. M., Dumas, J., & Larivière, C. (2016). The effects of an 8-week stabilization exercise program on lumbar movement sense in patients with low back pain. *BMC Musculoskeletal Disorders*, 17(1), 23. <https://doi.org/10.1186/s12891-016-0875-4>
7. Chang, D., Lui, A., Matsoyan, A., Safaee, M. M., Aryan, H. E., & Ames, C. (2024). Comparative Review of the Socioeconomic Burden of Lower Back Pain in the United States and Globally. *Neurospine*, 21(2), 487–501. <https://doi.org/10.14245/ns.2448372.186>
8. Chughtai, M. D. B., Shabbir, H., Basim, M., Rubab, U. e, MANZOOR, A., Ali, A., Khan, K., & Asim, H. A. B. (2025). Impact of Core Stabilization Exercises Versus Pilates on Pain Intensity, Lumbar Range of Motion, and Daily Activity Performance in Patients with Lumbar Disc Herniation: A Randomized Controlled Trial. *Journal of Health Wellness and Community Research*. <https://doi.org/10.61919/cxj8p995>
9. Clael, S., Campos, L. F., Correia, K. L., Lucena, J. M. S. de, Gentil, P., Durigan, J. L. Q., Ribeiro, A. L. de A., & Martins, W. R. (2021). Exercise interventions can improve muscle strength, endurance, and electrical activity of lumbar extensors in individuals with non-specific low back pain: a systematic review with meta-analysis. *Scientific Reports*, 11(1), 16842. <https://doi.org/10.1038/s41598-021-96403-7>
10. Collaborators, G. S. 2013, & A., B., Rupert R. (2015). Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. In HAL (Le Centre pour la Communication Scientifique Directe). Centre National de la Recherche Scientifique. <https://unilim.hal.science/hal-01285498>
11. Cunha, C., Silva, A. J., Pereira, P., Vaz, R., Gonçalves, R. M., & Barbosa, M. A. (2018). The inflammatory response in the regression of lumbar disc herniation. *Arthritis Research & Therapy*, 20(1), 251. <https://doi.org/10.1186/s13075-018-1743-4>
12. Dwan, K., Altman, D. G., Clarke, M., Gamble, C., Higgins, J. P. T., Sterne, J. A. C., Williamson, P., & Kirkham, J. J. (2014). Evidence for the Selective Reporting of Analyses and Discrepancies in Clinical Trials: A Systematic

Review of Cohort Studies of Clinical Trials. *PLoS Medicine*, 11(6).

<https://doi.org/10.1371/journal.pmed.1001666>

13. Fardon, D. F., Williams, A. L., Dohring, E. J., Murtagh, F. R., Rothman, S. L. G., & Sze, G. (2014). Lumbar disc nomenclature: version 2.0. *The Spine Journal*, 14(11), 2525–2545.
<https://doi.org/10.1016/j.spinee.2014.04.022>
14. Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149–1160.
<https://doi.org/10.3758/brm.41.4.1149>
15. Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191.
<https://doi.org/10.3758/bf03193146>
16. Faur, C. I., Pătrașcu, J. M., Haragă, H., & Anglitoiu, B. (2019). Correlation between multifidus fatty atrophy and lumbar disc degeneration in low back pain. *BMC Musculoskeletal Disorders*, 20(1), 414.
<https://doi.org/10.1186/s12891-019-2786-7>
17. Gillies, K., Kearney, A., Keenan, C., Treweek, S., Hudson, J., Brueton, V., Conway, T., Hunter, A., Murphy, L., Carr, P. J., Rait, G., Manson, P., & Aceves-Martins, M. (2021). Strategies to improve retention in randomised trials. *Cochrane Database of Systematic Reviews*, 2021(4). <https://doi.org/10.1002/14651858.mr000032.pub3>
18. Group, the C., Schulz, K. F., Altman, D. G., & Moher, D. (2010). CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. *BMC Medicine*, 8(1), 18. <https://doi.org/10.1186/1741-7015-8-18>
19. Gruijters, S. L. K. (2020). Baseline comparisons and covariate fishing: Bad statistical habits we should have broken yesterday. <https://doi.org/10.31234/osf.io/qftwg>
20. Gugliotta, M., Costa, B. R. da, Dabis, E., Theiler, R., Jüni, P., Reichenbach, S., Landolt, H., & Hasler, P. (2016). Surgical versus conservative treatment for lumbar disc herniation: a prospective cohort study. *BMJ Open*, 6(12). <https://doi.org/10.1136/bmjopen-2016-012938>
21. Hartvigsen, J., Hancock, M. J., Kongsted, A., Louw, Q., Ferreira, M. L., Genevay, S., Hoy, D., Karppinen, J., Pransky, G., Sieper, J., Smeets, R., Underwood, M., Buchbinder, R., Hartvigsen, J., Cherkin, D., Foster, N. E., Maher, C. G., Underwood, M., Tulder, M. W. van, ... Woolf, A. D. (2018). What low back pain is and why we need to pay attention. *The Lancet*, 391(10137), 2356–2367. [https://doi.org/10.1016/s0140-6736\(18\)30480-x](https://doi.org/10.1016/s0140-6736(18)30480-x)
22. Hidalgo, B., Detrembleur, C., Hall, T., Mahaudens, P., & Nielens, H. (2013). The efficacy of manual therapy and exercise for different stages of non-specific low back pain: an update of systematic reviews. *Journal of Manual & Manipulative Therapy*, 22(2), 59–74. <https://doi.org/10.1179/2042618613y.0000000041>
23. Hincapié, C. A., Kroismayr, D., Hofstetter, L., Kurmann, A., Cancelliere, C., Rampersaud, Y. R., Boyle, E., Tomlinson, G., Jadad, A. R., Hartvigsen, J., Côté, P., & Cassidy, J. D. (2024). Incidence of and risk factors for lumbar disc herniation with radiculopathy in adults: a systematic review. *European Spine Journal*, 34(1), 263–294. <https://doi.org/10.1007/s00586-024-08528-8>
24. Hlaing, S. S., Puntumetakul, R., Khine, E. E., & Boucaut, R. (2021). Effects of core stabilization exercise and strengthening exercise on proprioception, balance, muscle thickness and pain related outcomes in patients with subacute nonspecific low back pain: a randomized controlled trial. *BMC Musculoskeletal Disorders*, 22(1), 998. <https://doi.org/10.1186/s12891-021-04858-6>
25. Jamil, M., Bashir, M. S., Noor, R., Niazi, R., Ahmad, N., Ahmad, S., & Ahmad, H. (2023). Effects of Core Stabilization Exercises on Low Back Pain, Disability and Back Muscle Endurance in Patients with Lumbar Disc Herniation. *Annals of King Edward Medical University*, 29(2), 123–128.
<https://doi.org/10.21649/akemu.v29i2.5434>
26. Kanayama, M., Togawa, D., Takahashi, C., Terai, T., & Hashimoto, T. (2009). Cross-sectional magnetic resonance imaging study of lumbar disc degeneration in 200 healthy individuals. *Journal of Neurosurgery Spine*, 11(4), 501–507. <https://doi.org/10.3171/2009.5.spine08675>
27. Kang, H. (2021). Sample size determination and power analysis using the G*Power software. *Journal of Educational Evaluation for Health Professions*, 18, 17. <https://doi.org/10.3352/jeehp.2021.18.17>
28. Laird, R., Gilbert, J., Kent, P., & Keating, J. L. (2014). Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. *BMC Musculoskeletal Disorders*, 15(1), 229.
<https://doi.org/10.1186/1471-2474-15-229>

29. Manchikanti, L. (2000). Epidemiology of Low Back Pain. *Pain Physician*, 167–192. <https://doi.org/10.36076/ppj.2000/3/167>
30. Maniadakis, N., & Gray, A. (2000). The economic burden of back pain in the UK. *Pain*, 84(1), 95–103. [https://doi.org/10.1016/s0304-3959\(99\)00187-6](https://doi.org/10.1016/s0304-3959(99)00187-6)
31. McCaskey, M. A., Schuster-Amft, C., Wirth, B., Suica, Z., & Bruin, E. D. de. (2014). Effects of proprioceptive exercises on pain and function in chronic neck- and low back pain rehabilitation: a systematic literature review. *BMC Musculoskeletal Disorders*, 15(1), 382. <https://doi.org/10.1186/1471-2474-15-382>
32. Menon, V., Praharaj, S. K., & Andrade, C. (2024). Primary outcomes, secondary outcomes, and their relevance to how many papers are published from a study: A primer for authors, reviewers, and editors. *PubMed Central*, 66(5), 472–476. https://doi.org/10.4103/indianjpsychiatry.indianjpsychiatry_404_24
33. Mueller, J., & Niederer, D. (2020). Dose-response-relationship of stabilisation exercises in patients with chronic non-specific low back pain: a systematic review with meta-regression. *Scientific Reports*, 10(1), 16921. <https://doi.org/10.1038/s41598-020-73954-9>
34. Oosterhuis, T., Costa, L. O. P., Maher, C. G., Vet, H. C. W. de, Tulder, M. W. van, & Ostelo, R. (2014). Rehabilitation after lumbar disc surgery. *Cochrane Database of Systematic Reviews*, 2014(3). <https://doi.org/10.1002/14651858.cd003007.pub3>
35. Panjabi, M. M. (1992). The Stabilizing System of the Spine. Part I. Function, Dysfunction, Adaptation, and Enhancement. *Journal of Spinal Disorders*, 5(4), 383–389. <https://doi.org/10.1097/00002517-199212000-00001>
36. Peul, W. C., Houwelingen, H. C. van, Hout, W. B. van den, Brand, R., Eekhof, J., Tans, J. T. J., Thomeer, R. T. W. M., & Koes, B. W. (2007). Surgery versus Prolonged Conservative Treatment for Sciatica. *New England Journal of Medicine*, 356(22), 2245–2256. <https://doi.org/10.1056/nejmoa064039>
37. Prat-Luri, A., Rios-Calonge, J. de los, Moreno-Navarro, P., Manresa-Rocamora, A., Vera-García, F. J., & Barbado, D. (2023). Effect of Trunk-Focused Exercises on Pain, Disability, Quality of Life, and Trunk Physical Fitness in Low Back Pain and How Potential Effect Modifiers Modulate Their Effects: A Systematic Review With Meta-analyses. *Journal of Orthopaedic and Sports Physical Therapy*, 53(2), 64–93. <https://doi.org/10.2519/jospt.2023.11091>
38. Rantanen, J., Hurme, M., Falck, B., Alaranta, H., Nykvist, F., Lehto, M., Einola, S., & Kalimo, H. (1993). The Lumbar Multifidus Muscle Five Years After Surgery for a Lumbar Intervertebral Disc Herniation. *Spine*, 18(5), 568–574. <https://doi.org/10.1097/00007632-199304000-00008>
39. Roode, A. de, Heymans, M. W., Lankveld, W. van, & Staal, J. B. (2024). The impact of contextual effects in exercise therapy for low back pain: a systematic review and meta-analysis. *Research Square*. <https://doi.org/10.21203/rs.3.rs-4158946/v1>
40. Shang, Q., Yao, S., Ouyang, M., Wang, X., & Luo, S. (2025). Secondary Analysis of Randomized Controlled Trials: Methodological Considerations and Best Practices. *Annals of Clinical Epidemiology*, 7(4), 137–147. <https://doi.org/10.37737/ace.25017>
41. Shiga, Y. (2022). The Essence of Clinical Practice Guidelines for Lumbar Disc Herniation, 2021: 1. Epidemiology and Natural Course. *Spine Surgery and Related Research*, 6(4), 319–321. <https://doi.org/10.22603/ssrr.2022-0042>
42. Steffens, D., Maher, C. G., Pereira, L. S. M., Stevens, M. L., Oliveira, V. C., Chapple, M., Teixeira-Salmela, L. F., & Hancock, M. J. (2016). Prevention of Low Back Pain. *JAMA Internal Medicine*, 176(2), 199. <https://doi.org/10.1001/jamainternmed.2015.7431>
43. Tagliaferri, S. D., Miller, C. T., Owen, P. J., Mitchell, U. H., Brisby, H., Fitzgibbon, B. M., Massé-Alarie, H., Oosterwijk, J. V., & Belavý, D. L. (2019). Domains of Chronic Low Back Pain and Assessing Treatment Effectiveness: A Clinical Perspective. *Pain Practice*, 20(2), 211–225. <https://doi.org/10.1111/papr.12846>
44. Toerien, M., Brookes, S., Metcalfe, C., Salis, I. de, Tomlin, Z., Peters, T. J., Sterne, J. A. C., & Donovan, J. (2009). A review of reporting of participant recruitment and retention in RCTs in six major journals. *Trials*, 10(1), 52. <https://doi.org/10.1186/1745-6215-10-52>
45. Tugwell, P., Monsour, A., Marlin, S., Mayo-Wilson, E., Monga, S., Chee-A-Tow, A., Williamson, P., Golub, R., Thabane, L., Butcher, N. J., Offringa, M., Terwee, C. B., Grimshaw, J., Baba, A., Farid-Kapadia, M., Szatmári, P., Chan, A.-W., Ungar, W. J., Saeed, L., ... Gavin, F. (2024). Guidelines for Reporting Outcomes in Trial Reports: The CONSORT-Outcomes 2022 Extension. *UNC Libraries*. <https://doi.org/10.17615/fd6r-7956>

46. Vianin, M. (2008). Psychometric properties and clinical usefulness of the Oswestry Disability Index. *Journal of Chiropractic Medicine*, 7(4), 161–163. <https://doi.org/10.1016/j.jcm.2008.07.001>
47. VN, R. V., MJ, S., & Singh, V. (2021). Clinical profile of patients with lumbar disc prolapse. *National Journal of Clinical Orthopaedics*, 5(4), 28–30. <https://doi.org/10.33545/orthor.2021.v5.i4a.323>
48. Wang, Z., Liu, X., Gao, K., Tuo, H., Zhang, X., & Liu, W. (2024). Clinical effects and biological mechanisms of exercise on lumbar disc herniation. *Frontiers in Physiology*, 15, 1309663. <https://doi.org/10.3389/fphys.2024.1309663>
49. Yazıcı, A., & Yerlikaya, T. (2022). The relationship between the degeneration and asymmetry of the lumbar multifidus and erector spinae muscles in patients with lumbar disc herniation with and without root compression. *Journal of Orthopaedic Surgery and Research*, 17(1), 541. <https://doi.org/10.1186/s13018-022-03444-3>
50. Yoshihara, K., Shirai, Y., Nakayama, Y., & Uesaka, and S. (2001). Histochemical Changes in the Multifidus Muscle in Patients With Lumbar Intervertebral Disc Herniation. *Spine*, 26(6), 622–626. <https://doi.org/10.1097/00007632-200103150-00012>
51. Zeng, Z., Qin, J., Guo, L., Hirai, T., Gui, Z., Liu, T., Chen, S., Daiyang, Y., & Yan, M. (2023). Prediction and Mechanisms of Spontaneous Resorption in Lumbar Disc Herniation: Narrative Review. *Spine Surgery and Related Research*, 8(3), 235–242. <https://doi.org/10.22603/ssrr.2023-0152>
52. Zhao, W.-P., Kawaguchi, Y., Matsui, H., Kanamori, M., & Kimura, T. (2000). Histochemistry and Morphology of the Multifidus Muscle in Lumbar Disc Herniation. *Spine*, 25(17), 2191–2199. <https://doi.org/10.1097/00007632-200009010-00009>