INTERNATIONAL JOURNAL OF SOCIAL HEALTH
https://ijsh.ph/index.php/rp
**Volume 5 Number 1 January 2026**
E-ISSN: 2984-7079

# Comparative Effectiveness of Artificial Disc Replacement and Spinal Fusion in Lumbar Degenerative Disc Disease: A Systematic Review and Meta-Analysis

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**KEYWORDS**
Artificial disc replacement, Spinal fusion, Lumbar degenerative disc disease, Meta-Analysis

**ABSTRACT**
Lumbar Degenerative Disc Disease (LDDD) is a leading cause of chronic low back pain and disability. While surgery is considered when conservative treatments fail, traditional spinal fusion can lead to adjacent segment degeneration. Artificial Disc Replacement (ADR) was developed to preserve motion and reduce biomechanical stress, but evidence comparing ADR to spinal fusion is inconsistent. This systematic review and meta-analysis aimed to assess functional recovery, pain reduction, and reoperation rates between ADR and fusion. A comprehensive search of the literature up to 2025 was conducted across PubMed, ScienceDirect, Cochrane Library, and Google Scholar. Twelve studies involving 2,928 patients were analyzed. Results indicated that ADR provided superior outcomes in functional disability (ODI: MD = -2.59), pain reduction (VAS: MD = -2.15), and lower reoperation risk (RR = 0.60) compared to fusion, with minimal heterogeneity and low publication bias. No significant differences in overall complication rates were found, although patient satisfaction was generally higher with ADR. The findings suggest that ADR offers modest but meaningful benefits, particularly in function and reoperation risk, but long-term durability and cost-effectiveness remain uncertain. Further studies with longer follow-up are needed to confirm these results.

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## INTRODUCTION

Lumbar Degenerative Disc Disease (LDDD) is a progressive degenerative condition affecting the intervertebral discs, characterized by biochemical and structural deterioration that leads to loss of disc height, reduced elasticity, segmental instability, and chronic low back pain. Such degeneration contributes substantially to functional impairment, reduced quality of life, and a growing health burden globally (Binch et al., 2021; Kadow et al., 2015).

Low back pain (LBP), often a clinical manifestation of spinal degenerative disorders including LDDD, remains among the leading causes of disability worldwide (Wu et al., 2020). A recent comprehensive analysis based on the 2021 Global Burden of Disease (GBD) data estimated that the number of individuals living with LBP increased from approximately 386.7 million in 1990 to about 628.8 million in 2021 (Chen et al., 2024). Concurrently, while the age standardized prevalence per 100,000 population decreased modestly, the absolute number of cases rose markedly, underscoring the net expansion of LBP burden over time (Hartvigsen et al., 2018). The increasing global burden is driven by population growth, aging, and persistent

exposure to risk factors such as adverse ergonomics, female sex, and socio demographic factors (Knezevic et al., 2021).

Imaging and population-based studies show that disc degeneration is highly prevalent and increases with age (Teraguchi et al., 2014). For instance, in the population-based Wakayama Spine Study, the prevalence of intervertebral disc degeneration (evaluated by MRI using Pfirrmann grading) exceeded 90% in both men and women older than 50 years, illustrating how widespread structural spine degeneration becomes in older adults (Teraguchi et al., 2014). This high prevalence of radiographic degeneration suggests that a large proportion of adults are at risk for symptomatic LDDD or may already have underlying degenerative changes even if asymptomatic (Brinjikji et al., 2015).

Conservative management of LDDD, including non-steroidal anti-inflammatory drugs (NSAIDs), physical therapy, activity modification, and epidural injections is commonly employed as first line treatment (Knezevic et al., 2021). However, a significant subset of patients fails to achieve adequate or sustained relief, or progress toward chronic pain, disability, or radiographic deterioration, prompting consideration of surgical intervention (Mobbs et al., 2015). Spinal Fusion has long been considered the gold standard surgical treatment: by eliminating motion at the degenerated segment, fusion stabilizes the spine and aims to relieve pain arising from segmental instability (Phillips et al., 2015). Nonetheless, spinal fusion carries inherent limitations, including loss of physiological spinal mobility, risk of accelerated degeneration at adjacent segments (adjacent segment disease), pseudarthrosis, implant related complications, and prolonged rehabilitation (Salzmann et al., 2017).

To address these drawbacks, Artificial Disc Replacement (ADR) has been developed as a motion preserving alternative (Ding et al., 2017). ADR involves replacing the degenerated disc with a prosthetic implant designed to restore disc height, preserve motion at the involved segment, and more closely replicate the biomechanical function of a healthy disc under load, potentially maintaining spinal mobility, reducing stress on adjacent segments, enabling faster recovery, and improving long term functional outcomes (Wei et al., 2021).

Over the past two decades, multiple randomized controlled trials (RCTs) and observational cohort studies have compared ADR and Spinal Fusion in terms of pain relief, functional outcomes, radiographic parameters, complication rates, and reoperation rates (Skinner et al., 2020; Zigler et al., 2018). However, findings across these studies have sometimes varied, likely due to differences in prosthesis design, surgical technique, patient selection, follow up duration, and outcome measurements (Buttermann, 2018). As such, the relative advantages and long-term effectiveness of ADR versus Fusion remain debated, especially in light of evolving patient demographics and surgical technologies (Ziino et al., 2020).

Given the rising global burden of LBP and degenerative spine disease, magnified by demographic shifts toward older populations, increasing disc degeneration prevalence, and the high prevalence of radiographic degeneration in older adults, there is a critical need for a rigorous, up-to-date synthesis of existing evidence (Chen et al., 2024; Hartvigsen et al., 2018). This systematic review and meta-analysis aim to compare clinical effectiveness, pain reduction, functional improvement, and safety outcomes between ADR and Spinal Fusion in patients with

LDDD, thereby providing high level evidence to inform surgical decision-making, guide clinical practice, and support health policy development.

## METHODS

This review was carried out by identifying, assessing, and interpreting all findings related to scientific topics. The author used the PICOS (Population, Intervention, Comparison, Outcome, Studies) strategy to identify all relevant studies. All systematic search procedures follow the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines.

Eligible studies were identified through a systematic search of major electronic scientific databases, including PubMed, ScienceDirect, Cochrane Library, and Google Scholar. The search strategy was designed to retrieve clinical studies directly comparing Artificial Disc Replacement (ADR) and Spinal Fusion in adult patients diagnosed with lumbar degenerative disc disease.

Two reviewers independently conducted the screening process consisting of title, abstract, and full-text assessment. Study eligibility was determined based on predefined inclusion criteria: randomized controlled trials or cohort studies involving patients aged ≥18 years, direct comparison between ADR and fusion procedures, and availability of at least one of the following outcomes, Oswestry Disability Index (ODI), Visual Analog Scale (VAS) for pain assessment, or reoperation rates. Studies were excluded if they were non-comparative, review articles, case reports, or conference papers, included patients with cervical pathology, spinal deformity, trauma, infection, tumor, or prior lumbar surgery, evaluated hybrid constructs combining ADR and fusion or lacked complete or extractable quantitative outcome data. Only studies meeting the full methodological criteria were included in the qualitative synthesis and pooled meta-analysis.

A systematic search of the literature was conducted using a PICOS based framework to optimize identification of eligible studies. Medical Subject Headings (MeSH) terms were incorporated to refine terminology relevant to the research question. Advanced search strategies, including bibliographic screening and Boolean operators (AND, OR, NOT), were applied to combine specific keywords related to lumbar degenerative disc disease and surgical interventions. The core search string used was (“artificial disc replacement” OR “total disc replacement”) AND (“spinal fusion”) AND (“lumbar degenerative disc disease”), with additional filters implemented to target comparative clinical studies and relevant clinical outcomes. This search strategy was systematically applied across major electronic databases to ensure comprehensive evidence retrieval.

Data extraction in this review was performed independently by two reviewers using a standardized extraction sheet to ensure accuracy and consistency of collected variables, including study characteristics, patient demographics, intervention details, follow up duration, and clinical outcomes such as ODI, VAS, and reoperation rates. The methodological quality of each included study was critically evaluated to minimize bias. Randomized controlled trials were appraised using the Cochrane Risk of Bias 2 (RoB 2) tool, while observational cohort studies were assessed using the Newcastle–Ottawa Scale (NOS). Any disagreements between

reviewers were resolved through discussion or the involvement of a third reviewer when necessary. Only studies demonstrating acceptable methodological robustness and low to moderate risk of bias were included in the final analysis of this systematic review and meta-analysis.

Data analysis was performed by systematically synthesizing all extracted information to derive comprehensive conclusions regarding the comparative effectiveness of ADR and Spinal Fusion. Extracted variables included study characteristics (first author, publication year, study region), patient demographics, surgical intervention details, outcome assessment tools, and primary clinical results. A synthesis table was constructed to support structured evaluation and comparison across studies.

Quantitative meta-analysis was conducted using Review Manager (RevMan) version 5.4, applying mean difference (MD) for continuous outcomes (ODI, VAS) and risk ratio (RR) for dichotomous outcomes (reoperation rate). Statistical heterogeneity was assessed using the Chi square test along with $I^2$ and $Tau^2$ values, when substantial heterogeneity was detected, a random effects model was employed. Publication bias was evaluated visually using funnel plot symmetry. A p-value of $<0.05$ was considered statistically significant.

## RESULTS AND DISCUSSION

### Study Search

The initial identification process, drawing from databases and registers (PubMed, Science Direct, Cochrane, and Google Scholar), yielded a total of 531 records. Before screening, 13 records were removed: 11 were duplicates, and 2 were marked as ineligible by automation tools. This left 518 records to be screened. During the screening phase, 416 records were excluded, and the remaining 102 reports were sought for retrieval. Of these, 15 reports could not be retrieved.

The remaining 87 reports were then assessed for eligibility. A total of 75 reports were excluded at this stage (29 due to incomplete data and 46 due to irrelevant data). Consequently, the final review included 12 studies, represented by 12 reports of included studies. The study search flow using the PRISMA guideline is described as follows (Figure 1).

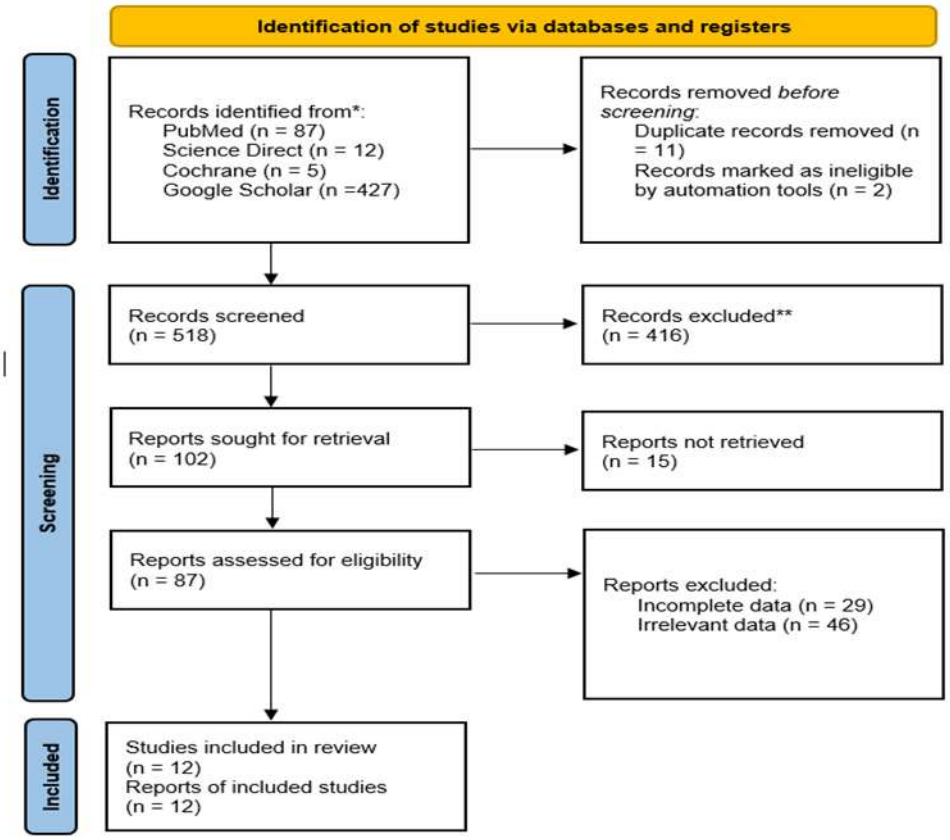


**Figure 1. Study search (PRISMA) flowchart**

## Study characteristics

The systematic review included 12 studies, all of which were Randomized Controlled Trials (RCTs). All included studies originated from the USA. The total pooled sample size across the studies was substantial, encompassing 1472 patients in the Artificial Disc Replacement (ADR) group and 970 in the Spinal Fusion group. Patients' mean ages in both groups generally ranged between 38 and 42 years. The follow-up duration was either 2 years or 5 years. The most common artificial disc types utilized were the Charité, ProDisc-L, and Maverick, while the primary fusion technique was Anterior Lumbar Interbody Fusion (ALIF). The procedures were mainly performed at the L4–L5 and L5–S1 spinal levels. Data on study characteristics can be seen in Table 1.

**Table 1. Study characteristics**

| Author (Year) | Country | Study Design | Sample Size (ADR/Fusion) | Mean Age (ADR/Fusion) | Sex (M/F) | Follow-up Duration | Artificial Disc Type | Fusion Technique | Spinal Level |
|---|---|---|---|---|---|---|---|---|---|
| **Blumenthal et al. (2005)** | USA | RCT | 304 (205/99) | 39.6 (8.16)/39.6 (9.07) | 157/147 | 2 years | Charité | ALIF | L4–L5/L5–S1 |
| **McAfee et al. (2005)** | USA | RCT | 304 (205/99) | 39.6 (8.16)/39.6 (9.07) | 157/147 | 2 years | Charité | ALIF | L4–L5/L5–S1 |

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| Author (Year) | Country | Study Design | Sample Size (ADR/Fusion) | Mean Age (ADR/Fusion) | Sex (M/F) | Follow-up Duration | Artificial Disc Type | Fusion Technique | Spinal Level |
|---|---|---|---|---|---|---|---|---|---|
| **Zigler et al. (2007)** | USA | RCT | 236 (161/75) | 38.7 (8.0)/40.4 (7.6) | 116/120 | 2 years | ProDisc-L | Circumferential Fusion | L3-S1 |
| **Holt et al. (2007)** | USA | RCT | 304 (205/99) | 39.6 (8.16)/39.6 (9.07) | 157/147 | 2 years | Charité | ALIF | L4–L5/L5–S1 |
| **Geisle et al. (2009)** | USA | RCT | 160 (111/49) | 40.1 (8.64)/37.8 (5.56) | 86/74 | 5 years | Charité | ALIF | L4–L5/L5–S1 |
| **Guyer et al. (2009)** | USA | RCT | 133 (90/43) | 40.0 (8.58)/38.8 (8.69) | 71/62 | 5 years | Charité | ALIF | L4–L5/L5–S1 |
| **Berg et al. (2009)** | USA | RCT | 152 (80/72) | 40.2 ± 8.1/38.5 ± 7.8 | 62/90 | 2 years | Charité, ProDisc-L, Maverick | PLIF | L3-S1 |
| **Gornet et al. (2011)** | USA | RCT | 577 (405/172) | 39.9 (18–70)/40.2 (18–65) | 291/286 | 2 years | Maverick | ALIF | L5–S1 |
| **Guyer et al. (2011)** | USA | RCT | 133 (90/43) | 40.0 (8.58)/38.8 (8.69) | 71/62 | 5 years | Charité | ALIF | L4–L5/L5–S1 |
| **Delamarter et al. (2011)** | USA | RCT | 237 (165/72) | 41.8 ± 7.73/41.8 ± 7.81 | 134/103 | 2 years | ProDisc-L | ALIF | L3-S1 |
| **Zigler et al. (2012)** | USA | RCT | 236 (161/75) | 38.7 (8.0)/40.4 (7.6) | 116/120 | 2 years | ProDisc-L | Circumferential Fusion | L3-S1 |
| **Skold et al. (2013)** | USA | RCT | 152 (80/72) | 40.2 ± 8.1/38.5 ± 7.8 | 62/90 | 5 years | Charité, ProDisc-L, Maverick | PLIF | L3-S1 |

## Study outcomes

Based on the study outcomes presented in the slides comparing Artificial Disc Replacement (ADR) and Spinal Fusion, the findings generally suggest that ADR is a comparable or superior treatment option for Lumbar Degenerative Disc Disease (LDDD). Across the included studies, ADR was consistently associated with faster and greater initial improvements in both functional disability (measured by the Oswestry Disability Index - ODI) and pain (Visual Analogue Scale - VAS) scores compared to fusion.

Furthermore, long-term data demonstrated that the ADR group maintained better functional outcomes, including retained segment motion and a higher rate of return to work. Crucially, the meta-analysis confirmed that ADR resulted in a statistically significant lower reoperation rate than Spinal Fusion, while both procedures had comparable rates of other major complications. The study outcomes are described in Table 2. Study outcomes.

**Table 2. Study outcomes**

| Study (Year) | Follow-up Duration | Outcomes |
|---|---|---|
| **Blumenthal et al. (2005)** | 2 years | The CHARITÉ™ artificial disc group demonstrated faster recovery and greater improvement in pain and disability compared with the fusion group. Patient satisfaction was higher, hospital stay was shorter, and reoperation rates were lower, while complication rates were similar between groups. |
| **McAfee et al. (2005)** | 2 years | Total disc replacement with the CHARITÉ™ artificial disc restored and maintained flexion-extension motion and disc height more effectively than anterior interbody fusion with BAK cages. The procedure showed less subsidence and better prosthesis function, with outcomes closely correlated to the accuracy of implant placement. |
| **Zigler et al. (2007)** | 2 years | The ProDisc-L artificial disc demonstrated safety and efficacy with no major complications. At 24 months, patients showed greater improvement in disability, neurological success, and satisfaction compared with the fusion group, with maintained motion and better functional scores. |
| **Holt et al. (2007)** | 2 years | Lumbar total disc replacement showed complication rates comparable to anterior lumbar interbody fusion, with no increase in major neurological or perioperative risks. The TDR group had a lower reoperation rate and minimal subsidence, emphasizing the importance of proper patient selection and surgical technique. |
| **Geisle et al. (2009)** | 5 years | Lumbar arthroplasty resulted in significant improvements in pain (VAS) and disability (ODI) across all subgroups, regardless of prior surgery or discectomy. In contrast, fusion patients with previous surgery or discectomy showed a trend toward poorer clinical and functional outcomes. |
| **Guyer et al. (2009)** | 5 years | At five-year follow-up, the CHARITÉ™ artificial disc demonstrated clinical outcomes comparable to fusion with BAK cages. Although pain and disability scores were similar between groups, the ADR group showed higher employment rates, lower long-term disability, and preserved spinal motion, supporting its noninferiority and functional advantages over fusion. |
| **Berg et al. (2009)** | 2 years | Total disc replacement showed faster improvement and a higher proportion of pain-free patients at one and two years compared with fusion. Although both groups achieved significant pain and disability reduction, the difference between treatments diminished by two years, with similar complication and reoperation rates. |
| **Gornet et al. (2011)** | 2 years | The investigational group receiving total disc replacement achieved superior outcomes in pain relief, disability improvement, and physical function compared with the fusion group. Patients returned to work sooner and experienced fewer implant-related complications, supporting the clinical superiority of disc replacement over fusion. |
| **Guyer et al. (2011)** | 5 years | The CHARITÉ™ total disc replacement group maintained significant improvements in pain and function at five years, comparable to or slightly better than fusion. Patients in the ADR group had fewer reoperations and lower long-term disability rates. Radiographic motion was preserved, supporting the long-term effectiveness of disc replacement. |
| **Delamarter et al. (2011)** | 2 years | Total disc replacement with ProDisc-L provided durable improvement in pain, function, and quality of life, comparable or superior to fusion. The ADR group showed fewer device-related complications and reoperations. Motion at the treated level was preserved, supporting the long-term safety and effectiveness of disc arthroplasty. |
| **Zigler et al. (2012)** | 2 years | Patients treated with ProDisc-L maintained significant improvement in pain and functional outcomes compared with the fusion group. Total disc replacement demonstrated higher overall success rates and fewer reoperations. Radiographic analysis confirmed preserved motion and stable implant performance over time. |
| **Skold et al. (2013)** | 5 years | Total disc replacement showed significantly better outcomes in pain relief and disability reduction compared with fusion. A higher proportion of TDR |

| | |
|---|---|
| | patients were completely pain-free, and quality-of-life scores were superior. Complication and reoperation rates were similar between groups, supporting the long-term safety and effectiveness of disc replacement. |

## Risk of Bias

The methodological quality of the included studies, assessed using the Cochrane Risk of Bias tool, revealed a mixed profile where the primary source of concern was related to Blinding of participants and personnel (Performance bias), which was at High risk across nearly all studies. This high risk is inherent to surgical trials due to the impossibility of blinding patients and surgical teams to the type of procedure (Artificial Disc Replacement vs. Fusion).

Another considerable limitation was found in the Other bias domain, with a significant number of studies being classified as high risk, often due to potential conflicts of interest like funding from device manufacturers. Conversely, the majority of studies demonstrated a Low risk of bias in several critical domains, including Random sequence generation and Allocation concealment (selection bias), as well as Blinding of outcome assessment (Detection bias) and Incomplete outcome data (Attrition bias). This suggests that the randomization process was generally robust and the assessment of primary subjective outcomes was protected from observer bias.

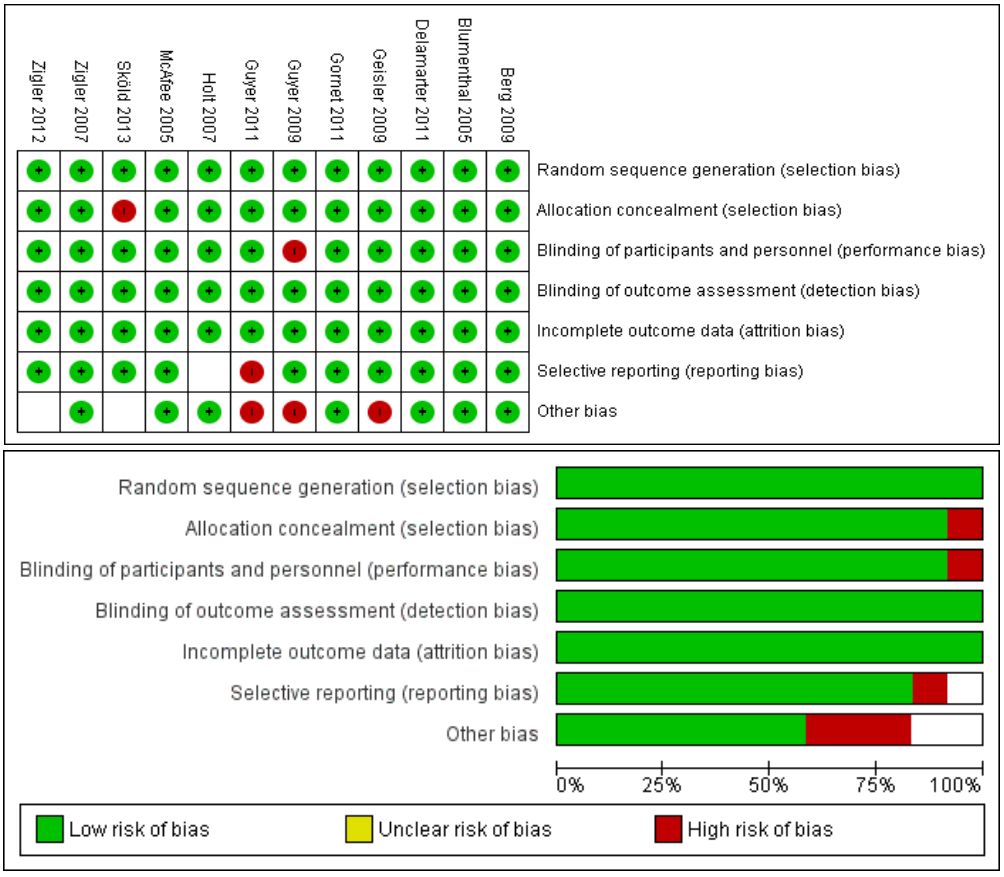


**Figure 2. Risk of Bias**

## Quantitative Analysis

### *Oswestry Disability Index*

The meta-analysis comparing Artificial Disc Replacement (ADR) and Spinal Fusion for lumbar degenerative disc disease showed that ADR is associated with a modest but statistically significant improvement in functional outcomes, as measured by the Oswestry Disability Index (ODI). The pooled Mean Difference was -2.59 (95% CI: -3.99 to -1.20, P= 0.0003), indicating lower disability scores in the ADR group. Heterogeneity across studies was minimal ($I^2$ = 0%, $Tau^2$ = 0.00, $Chi^2$ = 0.31, P = 1.00), and the funnel plot was symmetrical, suggesting a low risk of publication bias. These results suggest that ADR provides a small but consistent benefit over Spinal Fusion in reducing disability in patients with lumbar degenerative disc disease.

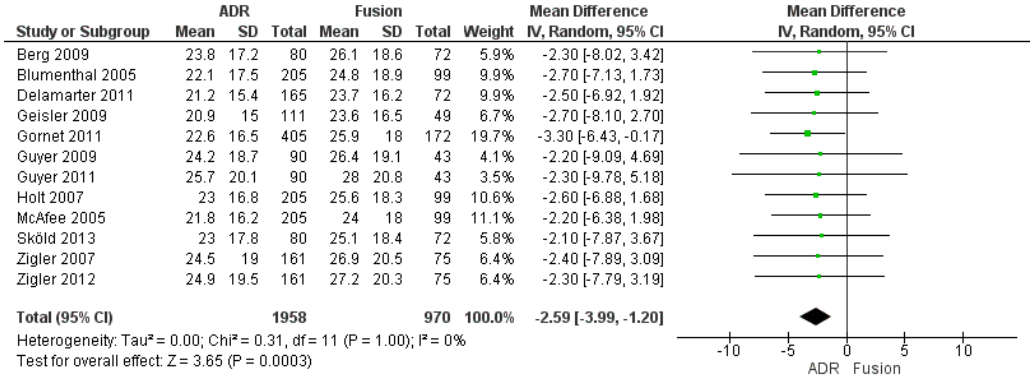


**Figure 3. Forest plot of Oswestry Disability Index**

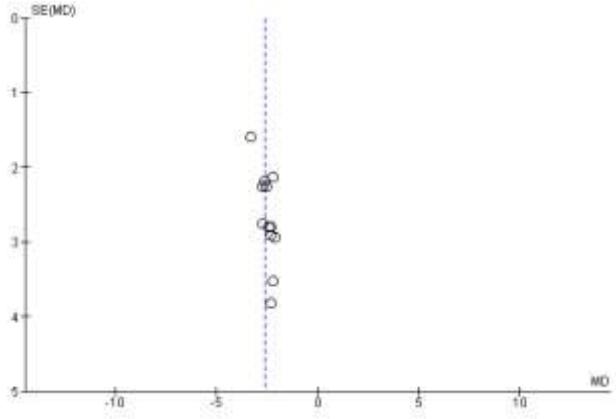


**Figure 4. Funnel plot of Oswestry Disability Index**

### *Visual Analog Scale*

The meta-analysis, encompassing 12 studies, demonstrated that Artificial Disc Replacement (ADR) resulted in a statistically significant greater reduction in VAS pain scores compared to Spinal Fusion, with a pooled Mean Difference of -2.15 (95% CI: -3.28 to -1.02, P= 0.0002). This finding is strongly supported by a very low level of heterogeneity across the studies ($I^2$=0% $Tau^2$ = 0.00, $Chi^2$ = 0.17, P = 1.00). The accompanying Funnel Plot displays good visual symmetry around the overall effect estimate, suggesting a low likelihood of substantial publication bias affecting the VAS outcome. The results of the Visual Analog Scale

can be seen in Figure 5. Forest plot of Visual Analog Scale and Figure 6. Funnel plot of Visual Analog Scale.

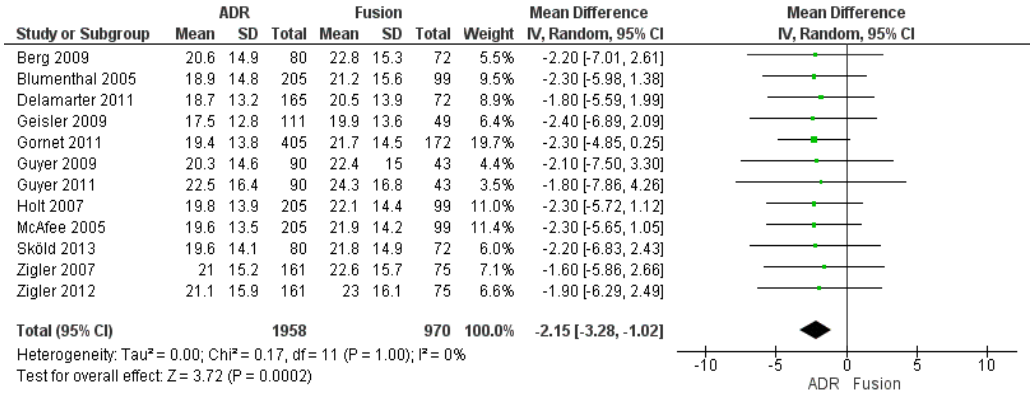


**Figure 5. Forest plot of Visual Analog Scale**

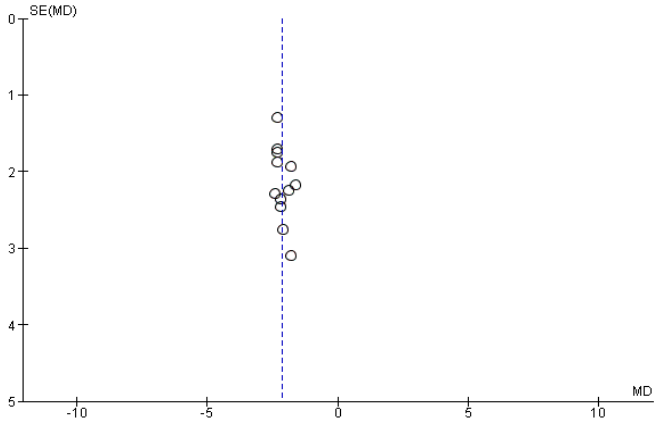


**Figure 6. Funnel plot of Visual Analog Scale**

***Reoperation***

The meta-analysis comparing Artificial Disc Replacement (ADR) and Spinal Fusion for lumbar degenerative disc disease demonstrated that ADR was associated with a significantly lower reoperation rate. The pooled Risk Ratio was 0.60 (95% CI: 0.40 to 0.91, P = 0.02). Heterogeneity was minimal ($I^2$ = 0%, $Chi^2$ = 2.78, P = 0.90), and the funnel plot appeared symmetrical, indicating a low likelihood of publication bias. These findings suggest that ADR reduces the risk of reoperation compared with Spinal Fusion, with consistent results across studies. The results of the Reoperation can be seen in Figure 7. Forest plot of Reoperation and Figure 8 . Funnel plot of Reoperation.

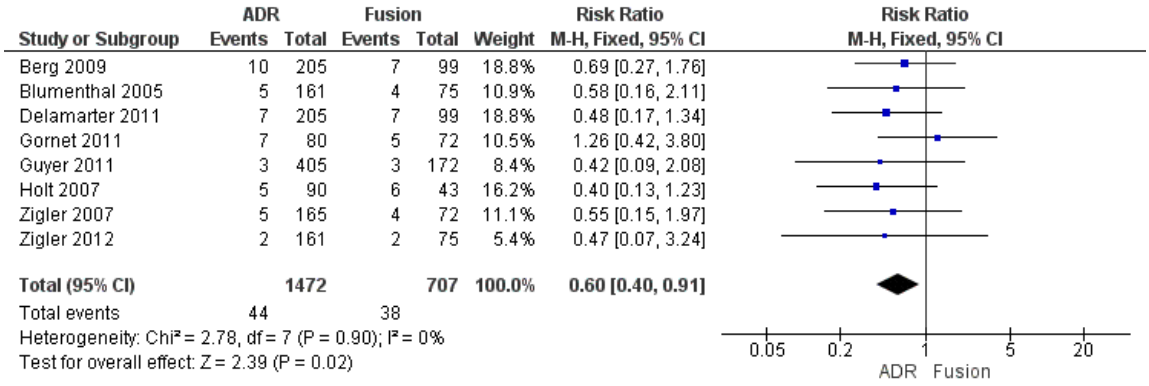


**Figure 7. Forest plot of Reoperation**

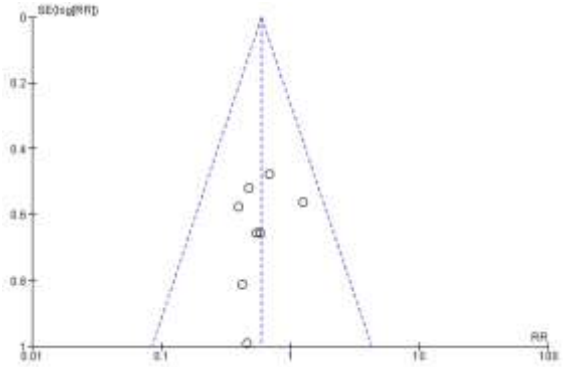

**Figure 8. Funnel plot of Reoperation**

The present meta-analysis combining data from 12 studies suggests that Artificial Disc Replacement (ADR) may offer modest but statistically significant advantages over spinal fusion in patients with lumbar degenerative disc disease (DDD). Our pooled results show a mean difference in the Oswestry Disability Index (ODI) of −2.59 (95% CI: −3.99 to −1.20; P = 0.0003), indicating lower disability post-operatively in the ADR group.

Similarly, for pain relief measured by the Visual Analog Scale (VAS), the pooled mean difference was −2.15 (95% CI: −3.28 to −1.02; P = 0.0002), favoring ADR. Furthermore, ADR was associated with a significantly lower reoperation rate (risk ratio 0.60; 95% CI: 0.40–0.91; P = 0.02). These findings are strengthened by negligible heterogeneity across studies ($I^2 = 0\%$, $Tau^2 = 0.00$) and symmetrical funnel plots suggesting low risk of publication bias.

These results align with prior high quality meta-analyses. A 2019 meta-analysis by Bai et al. (2019) reported that total disc replacement (TDR, equivalent to ADR) significantly improved ODI, VAS, patient satisfaction, and reduced reoperation compared with fusion.4 An updated systematic review in 2020 similarly found that TDR achieved better outcomes in functional status and pain relief than fusion, supporting ADR as a viable alternative to fusion in selected patients. Additionally, long-term follow-up data from observational studies indicate that lumbar disc prosthesis can provide durable pain relief, functional improvement, and high rates of occupational reintegration. For example, a 2025 study reported sustained

improvements in ODI and VAS, and a substantial proportion of patients returning to work after lumbar disc replacement.

The biomechanical reasoning for ADR's benefit lies in its motion-preserving design. By maintaining segmental mobility rather than eliminating it as in fusion ADR potentially avoids excessive stress on adjacent spinal levels, which has been implicated in adjacent-segment degeneration (ASD) after fusion. This motion preservation could explain the lower reoperation rates and long-term functional stability in ADR patients compared to fusion.

However, despite these statistically significant differences, the clinical significance of the observed effect sizes should be interpreted with caution. A mean ODI improvement of −2.59 points, though favorable, likely falls below commonly accepted thresholds for Minimal Clinically Important Difference (MCID) in lumbar spine surgery — which often require much larger changes (e.g., in the order of ~10 points) to reflect meaningful functional improvement for individual patients.9 Similarly, a VAS reduction of 2.15 points may not universally translate into substantial pain relief for all patients, particularly given variations in baseline pain, psychological status, and patient expectations (Bai et al., 2019; Li et al., 2020; Daher et al., 2024).

Long-term safety and durability remain critical concerns. While many mid-term studies are encouraging, some very long-term data show significant revision rates: one study found a 19.9% revision spinal fusion rate over 19.4 years in patients initially treated with lumbar disc prosthesis, highlighting risks of implant wear, subsidence, or late instability (Jordá-Gómez et al., 2025; Kitzen et al., 2020). Moreover, a recent 2024 meta-analysis comparing lumbar disc replacement with interbody fusion (IBF) found no statistically significant difference in reoperation, complication rates, or leg pain between the two groups though a slight advantage was noted for improved back pain in disc replacement patients. This suggests that in broader, real-world practice including patients with multilevel disease, comorbidities, or variable bone quality the benefits of ADR over fusion may be attenuated (Yang et al., 2025; World Health Organization [WHO], 2023; Teraguchi et al., 2014).

Economic considerations further complicate widespread adoption. Although ADR may reduce long term costs associated with reoperation and adjacent segment disease, the initial cost of prosthesis and surgery is often higher than fusion. Cost utility data remain limited, especially in diverse healthcare settings, and long term economic evaluations are largely lacking. Thus, for many healthcare systems especially those with limited resources the higher upfront cost may negate potential long-term savings, particularly when clinical benefit is modest.

Given these data and uncertainties, ADR may be best considered for a select subgroup of patients: relatively young, active individuals with single level lumbar disc disease, good bone quality, minimal comorbidities, and high demand for mobility and function. For patients with multilevel degeneration, spinal instability, poor bone quality, or complex comorbidities, spinal fusion likely remains the more reliable and predictable option. Shared decision making is essential, carefully weighing potential benefits, long term risks, patient expectations, and economic implications.

In conclusion, ADR represents a promising motion preserving alternative to fusion in lumbar DDD, offering modest improvements in disability and pain relief, along with lower reoperation rates. However, the small effect sizes, long term uncertainties, and cost considerations suggest that ADR should not yet replace fusion universally but rather be offered selectively, with patient centered decision making. Further long term, real world studies and cost effectiveness analyses are urgently needed to better define the role of ADR in lumbar spine surgery.

## CONCLUSION

Lumbar Degenerative Disc Disease (LDDD) is a leading cause of chronic low back pain and disability. While surgery is considered when conservative treatments fail, traditional spinal fusion can lead to adjacent segment degeneration. Artificial Disc Replacement (ADR) was developed to preserve motion and reduce biomechanical stress, but evidence comparing ADR to spinal fusion is inconsistent. This systematic review and meta-analysis aimed to assess functional recovery, pain reduction, and reoperation rates between ADR and fusion. A comprehensive search of the literature up to 2025 was conducted across PubMed, ScienceDirect, Cochrane Library, and Google Scholar. Twelve studies involving 2,928 patients were analyzed. Results indicated that ADR provided superior outcomes in functional disability (ODI: MD = -2.59), pain reduction (VAS: MD = -2.15), and lower reoperation risk (RR = 0.60) compared to fusion, with minimal heterogeneity and low publication bias. No significant differences in overall complication rates were found, although patient satisfaction was generally higher with ADR. The findings suggest that ADR offers modest but meaningful benefits, particularly in function and reoperation risk, but long-term durability and cost-effectiveness remain uncertain. Further studies with longer follow-up are needed to confirm these results.

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