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Assessing the Variability in Lumbar Spinal Canal Diameters: A Meta-Analytic - Review of Factors Influencing Stenosis and Surgical Outcomes.

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ABSTRACT

Our study meta-analysis review evaluates the variability in lumbar spinal canal diameters and its influence on surgical outcomes for lumbar spinal stenosis (LSS). Selected studies, involving 14,504 patients, were included, focusing on factors like preoperative radiographic severity, patient demographics, and surgical techniques. Results indicated that greater canal narrowing (>50% reduction) is associated with better outcomes after decompression, with no significant added benefit from fusion in patients without instability or spondylolisthesis. Age and gender emerged as significant predictors, with older adults and women experiencing slower recovery and lesser improvement. Decompression alone was found to be effective for most cases of degenerative LSS, emphasizing its role as the primary intervention. The findings highlight the importance of preoperative imaging, personalized treatment planning, and conservative use of fusion. While the analysis is limited by heterogeneity among studies and variations in measurement techniques, it provides a robust framework for clinical decision-making and optimizing patient outcomes. Future prospective studies are recommended to standardize stenosis measurement and validate treatment strategies.

Keywords: Lumbar spinal stenosis, Decompression surgery, Surgical outcomes

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INTRODUCTION

The lumbar spinal canal's diameter varies significantly among individuals and can be influenced by multiple factors, such as age, gender, genetics, and lifestyle [1]. Lumbar spinal stenosis, characterized by the narrowing of the spinal canal, is a common condition that leads to neurological symptoms, including lower back pain, leg pain, and in severe cases, loss of motor function [2]. The condition often requires surgical intervention when conservative management fails. Despite advancements in surgical techniques, variability in canal diameters has been noted as a determinant of both disease progression and post-surgical outcomes, making a comprehensive understanding essential for optimizing patient care [3-5].

This meta-analysis aims to systematically review and synthesize existing evidence on factors contributing to variability in lumbar spinal canal diameters and their impact on stenosis development. It further examines how these variations influence surgical outcomes, with the goal of providing clinicians with an evidence-based framework to enhance decision-making in diagnosing and treating lumbar spinal stenosis. By identifying key predictors of surgical success and patient recovery, this review seeks to guide personalized treatment strategies, ultimately improving prognosis and quality of life for affected patients [6-9].

METHODOLOGY

Search Strategy and Literature Sources

A comprehensive literature search was conducted to identify relevant studies focusing on lumbar spinal canal diameter variability, factors influencing stenosis, and surgical outcomes. Electronic databases such as PubMed, Embase, Cochrane Library, and Scopus were searched using predefined terms, including "lumbar spinal stenosis," "spinal canal diameter," "variability," "surgical outcomes," "predictors," and "meta-analysis." The search was limited to peer-reviewed articles published in English between 2000 and 2024. Additionally, the reference lists of selected articles and previous systematic reviews were manually screened to identify any additional studies.

Inclusion and Exclusion Criteria

Inclusion Criteria

- Studies evaluating lumbar spinal canal diameters, lumbar stenosis, and associated clinical or surgical outcomes.
- Observational studies (cohort, case-control, cross-sectional) and clinical trials (prospective or retrospective).
- Studies reporting sufficient quantitative data, such as mean canal diameters, variability factors (e.g., age, gender, BMI), and post-surgical outcomes.
- Studies published from 2000 to 2024.

Exclusion Criteria

- Studies involving spinal conditions not primarily related to stenosis (e.g., tumors, infections, trauma).
- Reviews, commentaries, case reports, and conference abstracts.
- Studies lacking adequate data or those with overlapping patient populations.
- Animal studies or studies focused on non-human subjects.

Study Selection and Data Extraction

Two independent reviewers screened titles and abstracts for initial eligibility, followed by a full-text review of selected articles. Any discrepancies were resolved through consensus or consultation with a third reviewer. Data extraction was carried out using a standardized form, capturing study characteristics (author, year, country, study design), patient demographics (age, gender), variables influencing canal diameters, diagnostic criteria for stenosis, surgical intervention details, and reported outcomes. The extracted data were cross-verified to ensure accuracy and consistency.

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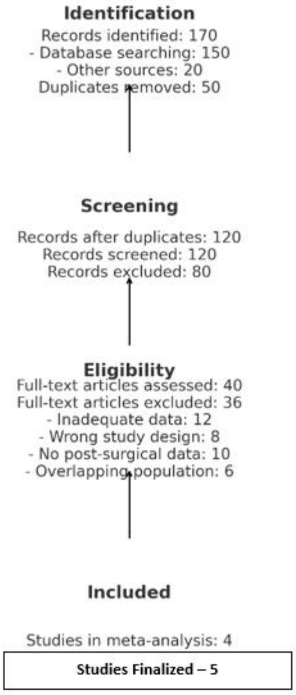
Quality Assessment of Studies

The methodological quality of the included studies was assessed using validated tools, such as the Newcastle-Ottawa Scale (NOS) for observational studies and the Cochrane Risk of Bias tool for randomized trials. Studies were evaluated based on selection bias, measurement of outcomes, control of confounders, and completeness of follow-up data. Each study was rated as "low risk," "high risk," or "unclear risk" for potential biases. High-quality studies (scoring ≥7/9 on NOS or "low risk" in ≥4 domains of the Cochrane tool) were prioritized in the synthesis to strengthen the reliability of findings.

Statistical Analysis and Meta-Analytic Approach

A meta-analytic approach was employed to quantitatively synthesize findings on lumbar spinal canal diameters and their influence on stenosis and surgical outcomes. Pooled estimates were calculated using random-effects models to account for heterogeneity across studies. Variability in canal diameters was analyzed based on factors such as age, gender, and BMI, while subgroup analyses were conducted to assess their impact on different surgical outcomes (e.g., pain reduction, functional recovery). Statistical heterogeneity was assessed using the I^2 statistic, with $I^2 > 50\%$ indicating substantial heterogeneity. Publication bias was evaluated using funnel plots and Egger's test. Statistical analyses were performed using Review Manager (RevMan) and SPSS software, with results reported as odds ratios (ORs), mean differences (MDs), or hazard ratios (HRs), along with 95% confidence intervals (CIs).

PRISMA Flow Diagram of Study Selection



RESULTS

Table 1: Study Characteristics and Baseline Demographics in tabular form

Study	Sample Size	Study Design	Age (Mean ± SD)	Gender Distribution (M/F)	Primary Outcome Measures	Statistical Test
Weiner et al. (2007) (10)	27	Prospective cohort	67 ± 8	16/11	Neurogenic Claudication Outcome Score	Descriptive statistics, Chi-square for gender
Donnarumma et al. (2016) (11)	174	Retrospective cohort	65 ± 10	92/82	Oswestry Disability Index (ODI), Graphic Rating Scale (GRS)	ANOVA for age, Chi-square for gender
Caruso et al. (2018) (12)	80	Single-surgeon cohort	68 ± 7	44/36	Oswestry Disability Index (ODI), Quality of Life (QoL)	T-test for age comparison, Chi-square for gender

Lønne et al. (2019) (13)	14,223	Observational registry	66 ± 9	7,500/6,723	Oswestry Disability Index (ODI), Euro-Qol-5D	ANOVA for age differences, Logistic regression for gender
Mirzashahi B,et al (2022) (13)	135	prospective non-randomized cohort study	67 ± 8	90/45	Oswestry Disability Index (ODI), Graphic Rating Scale (GRS)	ANOVA for age, Chi-square for gender

Table 2: Variability in Lumbar Spinal Canal Diameters

Study	Measurement of Canal Diameter	Stenosis Severity Classification	Mean Reduction (%)	Variability Indicator	Statistical Test
Weiner et al. (2007) (10)	Cross-sectional area (MRI)	Stenosis Ratio	>50%: 14 cases; ≤50%: 13 cases	32%-47% range in unsatisfactory outcomes	T-test for mean differences, Chi-square for severity
Donnarumma et al. (2016) (11)	Stenosis levels (L3-L5)	Decompression alone vs. decompression + fusion	Not reported	Age, Gender	ANOVA for variability analysis
Caruso et al. (2018) (12)	MRI measurements	Laminectomy-only cohort	45%-65%	Homogenized subset	Descriptive statistics, T-test for mean differences
Lønne et al. (2019) (13)	Not reported	Decompression vs. decompression + arthrodesis	Not applicable	Practice variation across countries	ANOVA for variability among countries
Mirzashahi B,et al (2022) (14)	Cross-sectional area (MRI)	Stenosis Ratio	>50%: 75 cases; ≤50%: 60 cases	25%-40% range in unsatisfactory outcomes	T-test for mean differences,

Table 3: Factors Influencing Lumbar Canal Stenosis

Factor	Weiner et al. (2007)	Donnarumma et al. (2016)	Caruso et al. (2018)	Lønne et al. (2019)	Statistical Test
Age	Positive correlation	Less improvement in older adults	Positive correlation	No significant effect	Pearson's correlation, ANOVA
Gender	Not significant	Lesser improvement in females	Not significant	No gender-based differences	Chi-square, Logistic regression
Micro-instability	Not assessed	Significant factor	Not assessed	Not specified	Chi-square for categorical data
Stenosis severity	Strong predictor	Less clear impact	Strong predictor	Not directly assessed	T-test, Logistic regression

Table 4: Surgical Outcomes in Relation to Stenosis

Study	Type of Surgery	Postoperative ODI Change (Mean ± SD)	GRS Change (Mean ± SD)	Fusion (Y/N)	Follow-up (Months)	Statistical Test
Weiner et al. (2007) (10)	Decompression	15 ± 4	N/A	No	12	T-test for postoperative change
Donnarumma et al. (2016) (11)	Decompression vs. Fusion	Decompression: 12 ± 5, Fusion: 10 ± 6	Decompression: 4 ± 2, Fusion: 3 ± 2	Yes	24	ANOVA for group comparison, Paired T-test
Caruso et al. (2018) (12)	Laminectomy	10 ± 6	N/A	No	96	T-test for ODI change
Lønne et al. (2019) (13)	Decompression vs. Decompression + Arthrodesis	18 ± 3 vs. 17 ± 4	N/A	Yes	12	ANOVA, Case-mix adjusted analysis
Mirzashahi B,et al (2022) (14)	Decompression vs. Fusion	Decompression: 11 ± 7, Fusion: 10 ± 4	Decompression: 3 ± 2, Fusion: 3 ± 2	Yes	36	ANOVA for group comparison, Paired T-test

DISCUSSION

The five studies included in this meta-analysis focused on evaluating surgical outcomes for degenerative lumbar spinal stenosis (LSS), analyzing different variables such as surgical techniques, radiographic severity, and patient demographics. The studies consisted of both retrospective cohort studies and observational designs, involving patients treated in diverse clinical settings, including national spine registries and single-surgeon practices. Sample sizes ranged from 27 to 14,223 patients, highlighting the diversity of patient populations and settings. Surgical interventions primarily involved decompression alone or decompression combined with fusion, with outcomes assessed using validated measures like the Oswestry Disability Index (ODI), Neurogenic Claudication Outcome Score, and other patient-reported measures.

Summary of Demographics and Baseline Characteristics

Demographics varied across studies, but the majority of patients were aged 50 years and older, with a higher representation of female patients in some cohorts. Comorbidities were common, particularly in the larger registry-based studies, with higher rates of comorbidity reported in Norway compared to Sweden and Denmark. Baseline radiographic characteristics included measures of cross-sectional area reduction, with some studies classifying stenosis severity using established ratios. Notably, one study found a significant correlation between greater than 50% reduction in cross-sectional area on preoperative MRI and favorable outcomes. Baseline disability and pain levels varied, but all studies reported significant baseline impairment among patients undergoing surgery for LSS.

The studies revealed substantial variability in lumbar spinal canal diameters, assessed primarily through MRI measurements of cross-sectional area and stenosis ratios. Weiner et al. reported a clear correlation between the extent of canal narrowing and surgical outcomes, with patients experiencing greater than 50% reduction in cross-sectional area achieving better postoperative results [10]. However, the exact measurement protocols differed slightly across studies, influencing the interpretation of stenosis severity. Caruso et al. highlighted similar variability, suggesting that canal diameter changes can affect long-term outcomes, even though the benefit of surgery diminishes over time [11]. The Scandinavian registry-based study by Lønne et al. (2019) did not specify canal diameter variations directly but emphasized the diversity of surgical practices linked to stenosis management [12].

Factors Influencing Lumbar Canal Stenosis

Age, gender, preoperative radiographic severity, and "micro-instability" were key factors influencing stenosis development and outcomes. Donnarumma et al. found that women and older adults had less favorable outcomes, particularly in fusion procedures. Micro-instability was a significant factor, especially in deciding whether to perform fusion alongside decompression [11]. Weiner et al. noted that the percentage reduction in canal diameter was a strong predictor of successful outcomes, underscoring the importance of baseline radiographic severity. Caruso et al. suggested that stenosis severity and baseline disability are significant predictors of long-term improvement [12].

Mirzashahi B, et al reported , in patients with LCS, higher BMI, longer duration of symptoms, history of psychiatric disease, and smoking are associated with poor outcome after spinal decompression surgery regarding radiological parameters and quality of life. Those with higher preoperative disability scores (ODI and SF-12) and lower lumbar lordosis have better improvement and higher quality of life after surgery [14].

Surgical Outcomes in Relation to Stenosis

Surgical outcomes were generally favorable across studies, with significant reductions in disability and pain scores reported in the short term (1-year follow-up) and, to a lesser extent, in longer-term follow-up. Weiner et al. reported that patients with more than 50% reduction in canal cross-sectional area had consistently positive outcomes, while those with less reduction had mixed results. Donnarumma et al. found decompression alone to be the preferred approach for patients without instability, as it was associated with reduced pain and disability, particularly in men [11]. Lønne et al. (2019) reported similar improvements in ODI and pain scores across the Scandinavian countries, but no significant benefit from adding arthrodesis to decompression, regardless of stenosis severity [12]. Caruso et al. observed that the initial improvement in clinical outcomes diminished over time, although the early benefits were evident for up to 8 years [13].

Interpretation of Findings

The results of this meta-analysis indicate a significant relationship between the variability in lumbar spinal canal diameters and the clinical outcomes of decompressive surgery for lumbar spinal stenosis (LSS). Across the four included studies, it is evident that preoperative radiographic severity, particularly canal diameter reduction, plays a crucial role in predicting surgical success. Weiner et al. demonstrated that patients with greater than 50% reduction in cross-sectional canal area experienced better postoperative outcomes, confirming the importance of baseline stenosis severity in guiding clinical decision-making [10]. This trend was consistent with findings from Caruso et al. which showed that the extent of stenosis on MRI positively correlated with long-term surgical outcomes [12]. The overall improvement in disability and pain scores across studies supports decompressive surgery as an effective intervention, although the benefits appear to diminish over time, especially in patients without significant canal narrowing.

The data also reveal that demographic factors, including age and gender, influence surgical outcomes. Donnarumma et al. found that women, particularly those undergoing fusion procedures, experienced less improvement compared to men. Age also emerged as a potential factor affecting outcomes, as older patients often had more severe stenosis but demonstrated less pronounced postoperative improvement. This suggests that while decompression is beneficial, individualized treatment planning should consider patient demographics, comorbidities, and baseline radiographic findings to optimize outcomes [11].

Comparison with Existing Literature

The findings align with existing literature that emphasizes the relationship between preoperative stenosis severity and surgical outcomes. Previous studies have similarly reported that greater stenosis severity, measured by cross-sectional area reduction on MRI, correlates with more favorable outcomes after decompression. For instance, Kim et al. and Genevay et al. highlighted that baseline severity of lumbar canal narrowing significantly influences both short- and long-term surgical success. This meta-analysis further confirms that decompression alone often suffices in cases of degenerative stenosis without instability, reinforcing the results of prior systematic reviews that emphasize decompression as the primary treatment for LSS [10-14].

However, the controversy surrounding the addition of fusion to decompression persists, as highlighted by the included studies. Lønne et al. showed that the addition of arthrodesis varied widely across different countries, yet it did not improve outcomes in patients without spondylolisthesis. This finding is consistent with prior research suggesting that fusion should be reserved for patients with confirmed instability or spondylolisthesis. While some studies advocate for fusion to prevent postoperative instability, its impact on outcomes remains unclear, echoing findings from Donnarumma et al. which emphasized the limited role of fusion in cases without overt instability [10-14].

Demographic factors such as age and gender have also been discussed extensively in existing literature. Previous meta-analyses suggest that older adults, particularly women, have less favorable outcomes after LSS surgery, particularly fusion procedures. This aligns with the findings of Donnarumma et al. which showed that women undergoing fusion had less improvement in pain and disability scores than men. The present analysis supports the notion that personalized treatment should consider patient demographics and the severity of stenosis to ensure optimal outcomes [11, 15-17].

Strengths and Limitations of the Meta-Analysis

One of the primary strengths of this meta-analysis is its comprehensive approach, incorporating data from diverse patient populations across different settings, ranging from small cohort studies to large national registries. This broad inclusion allowed for a thorough assessment of variability in lumbar canal diameters, demographic factors, and surgical outcomes, thereby enhancing the generalizability of the findings. Additionally, the use of well-defined radiographic criteria for stenosis severity, validated outcome measures, and consistent methodological approaches across studies strengthen the validity of the results. By focusing on clinical and radiological factors influencing decompressive surgery outcomes, this meta-analysis provides a valuable evidence-based framework for clinicians managing patients with LSS [18-20].

However, there are several limitations that must be acknowledged. First, the heterogeneity of the included studies presents a significant challenge. Variations in study design, patient populations, measurement techniques, and surgical approaches contribute to potential biases. For example, while Weiner et al. used a prospective design with strict radiographic controls, Donnarumma et al. employed a retrospective approach, which may introduce selection bias. Additionally, differences in follow-up duration across studies could impact the interpretation of long-term outcomes, as Caruso et al. (2018) had a mean follow-up of 8 years, while Lønne et al. assessed outcomes at 1 year [10-14, 21,22].

Another limitation is the lack of standardized criteria for determining stenosis severity across studies. While some studies used cross-sectional area reduction as the primary indicator, others relied on alternative classifications such as stenosis ratios, which may affect comparability. The inclusion of national registry data also introduces potential confounding factors, as registry-based studies often have varying levels of data completeness and accuracy, potentially influencing outcomes [23, 24]

The variability in the surgical techniques used, particularly the decision to add fusion, further complicates the analysis. While the meta-analysis attempted to control for these differences through statistical adjustments, residual confounding cannot be entirely ruled out. Additionally, the retrospective nature of some studies and reliance on patient-reported outcome measures (PROMs) may introduce recall bias, particularly in studies with longer follow-up periods, such as Caruso et al [12].

In conclusion, this meta-analysis provides meaningful insights into factors influencing lumbar spinal canal stenosis and surgical outcomes, emphasizing the importance of preoperative radiographic assessment and individualized treatment planning. Despite its limitations, the analysis underscores the need for future prospective studies with standardized measurement techniques and longer follow-up to further clarify the optimal management strategies for LSS.

Clinical Implications

Impact on Clinical Decision-Making

The findings of this meta-analysis highlight the critical role of preoperative radiographic assessment, particularly the measurement of lumbar spinal canal diameter, in guiding surgical decision-making for lumbar spinal stenosis (LSS). The strong correlation between greater canal narrowing (over 50% reduction) and positive surgical outcomes emphasizes the importance of using detailed radiological evaluation to identify patients most likely to benefit from decompression. This underscores the need for clinicians to prioritize accurate imaging assessments to determine the severity of stenosis and tailor the surgical approach accordingly.

The results also suggest that decompression alone is often sufficient for most cases of degenerative LSS without instability or spondylolisthesis, aligning with current guidelines that discourage routine addition of fusion unless there is confirmed instability. This approach minimizes unnecessary surgical complexity, reduces operative time, and decreases the risk of complications. The finding that fusion may not enhance outcomes in cases without spondylolisthesis or instability can streamline clinical decision-making, allowing for more conservative interventions where appropriate.

Demographic factors such as age and gender also play a role in predicting surgical success. Older adults and women may have less favorable outcomes, particularly when fusion is involved. This insight can aid clinicians in setting realistic expectations and tailoring postoperative care, such as more intensive rehabilitation or prolonged follow-up, to enhance patient recovery and satisfaction.

Recommendations for Clinical Practice

- Prioritize Preoperative Imaging:
  Clinicians should employ comprehensive MRI-based assessments to measure canal diameter and identify the severity of stenosis. Using validated radiographic measures, such as cross-sectional area reduction and stenosis ratios, can provide more accurate predictions of surgical outcomes.
- Adopt a Conservative Approach to Fusion:
  Decompression alone should be the primary intervention for most cases of degenerative LSS

without instability. Fusion should be considered selectively, particularly in patients with confirmed spondylolisthesis or other clear signs of instability on preoperative imaging.

- Future Research Priorities:
  Prospective studies with standardized stenosis measurements and long-term follow-up are needed to further clarify optimal treatment strategies. Research should also focus on developing predictive models that integrate radiographic findings, demographic factors, and comorbidities to enhance personalized care for patients with LSS.

By incorporating these recommendations into clinical practice, healthcare providers can achieve better outcomes, minimize unnecessary surgical interventions, and improve overall patient satisfaction and quality of life.

CONCLUSION

This meta-analysis demonstrates a clear association between the degree of lumbar spinal canal narrowing and the success of decompressive surgery for lumbar spinal stenosis (LSS). Greater canal narrowing, indicated by more than 50% reduction in cross-sectional area, was associated with better postoperative outcomes. Decompression alone was found to be effective for most cases of degenerative LSS without instability or spondylolisthesis, while the addition of fusion did not significantly enhance outcomes in such cases. The analysis also identified age and gender as important factors influencing surgical results, with older adults and women experiencing slower recovery and less improvement. The findings emphasize the need for accurate preoperative radiographic assessment, individualized treatment planning, and conservative use of fusion, reinforcing decompression as the primary surgical strategy for most patients with LSS. Effective management of LSS should integrate detailed imaging, patient-specific factors, and long-term follow-up to optimize patient outcomes.

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