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REVIEW

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Influence of prone, supine, and lateral positions during spine surgery on vascular, abdominal, and postural anatomy: a comprehensive review and Bayesian meta-analysis

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Abstract

Background Patient positioning alters the three-dimensional relationship between the spine and surrounding neurovascular and visceral structures, thereby influencing both the technical feasibility and safety of lumbar procedures. Quantitative estimates of these positional shifts remain heterogeneous.

Objective To determine, across contemporary imaging studies, how prone, supine, and lateral decubitus positions alter the displacement of great vessels and retroperitoneal organs, the location of the psoas/lumbar plexus, and segmental lumbar lordosis.

Methods MEDLINE, Embase, and CENTRAL were searched from 2015 to 2025. Eligible studies compared at least two positions in adults and reported millimetre or degree differences for the outcomes of interest. Random-effects (REML) subgroup meta-analyses, a graph-theoretical network meta-analysis (netmeta), leave-one-out diagnostics, and Bayesian sensitivity models were performed. Risk of bias was assessed with ROBINS-I.

Results Nine studies (41 independent comparisons; $n = 1{,}248$) met inclusion criteria. Retro-peritoneal organs moved posteriorly by a pooled + 6.34 mm (95% CI 1.87–10.80; $p = 0.007$) when patients were turned from lateral decubitus to the prone position, narrowing the anterior working corridor at L2–L4. No significant pooled displacement was detected for major vessels (+ 1.26 mm, 95% CI −2.43–4.94), psoas/plexus (+ 0.94 mm, 95% CI −3.58–5.46) or segmental lordosis (+ 1.55°, 95% CI −4.62–7.73°). Direct contrasts showed that the supine-to-prone transition increased combined displacement/lordosis by + 3.64 mm / °(95% CI 0.53–6.76). Network ranking favoured the supine position for anatomical stability, but inconsistency was high ($I^2 = 89\%$). Two studies were low, three moderate, three serious and one critical risk of bias; removing serious/critical studies did not change the effect direction.

Conclusions Turning a patient prone produces a reproducible posterior migration of the colon and kidney (6 mm) and a modest increase in lumbar lordosis (3–4°). Vascular and psoas positions are highly patient-specific and cannot be assumed based on supine imaging alone. Preoperative planning should therefore incorporate position-matched

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imaging or intraoperative navigation, especially for anterior or anterolateral approaches at L2–L4. Further high-quality, multi-positional imaging studies are warranted to clarify the sources of the marked heterogeneity observed.

Keywords Lumbar spine, Patient positioning, Prone position, Lateral decubitus, Vascular displacement, Retroperitoneal organs, Lordosis, Meta-analysis

Introduction

The surgical positioning of patients during spine surgery is a crucial determinant of the procedure's success [1–10]. Different positions (prone, supine, and lateral) offer unique benefits and challenges, particularly in relation to the anatomy of vascular structures, abdominal contents, and the musculoskeletal system [9, 11–15]. For instance, the prone position is favoured for posterior spinal approaches due to the enhanced access it provides, but requires careful consideration of how it affects internal structures [14, 16–19]. Conversely, the supine position is traditionally used for anterior approaches, offering stability but limited flexibility for posterior manipulations [20–24]. The lateral position, increasingly employed for lateral lumbar interbody fusion (LLIF), oblique anterior lumbar interbody fusion (OLIF), lateral anterior lumbar interbody fusion (LALIF) and single-position lumbar surgeries combining lateral and dorsal procedures simultaneously, presents its challenges, particularly regarding the displacement of major vessels and abdominal organs compared to supine MRI findings [12, 25–40].

Proper surgical positioning is crucial for minimising the risk of complications, optimising surgical access, and ensuring patient safety [5, 11, 41–48]. Different positions alter the body's anatomy in specific ways, impacting the surgeon's ability to access target areas, maintain the stability of vital structures, and reduce the risk of inadvertent injury [49]. With the advent of modern surgical techniques, particularly in lateral and anterior lumbar procedures performed in prone or lateral decubitus positions, or combined single-position dorsoventral simultaneous surgeries, these positional considerations become increasingly important. This is especially true in complex spine surgeries, where precision is essential for achieving optimal outcomes.

This review aims to provide a comprehensive analysis of how prone, supine, and lateral positions impact vascular anatomy, abdominal content displacement, and postural alignment during spine surgery. By synthesising findings from multiple studies and conducting a detailed meta-analysis, we aim to provide evidence-based recommendations that inform clinical practice and enhance patient outcomes.

Methods

Literature search strategy

We conducted an updated literature search across multiple databases covering 10 years (January 2015 through March 2025) to ensure all relevant studies were captured. The search included PubMed, MEDLINE (via Ovid), and the Cochrane Library for studies on patient positioning in spine surgery. We combined keywords and medical subject headings related to spinal surgery and patient positioning (e.g., "spine surgery", "lumbar fusion", "prone position", "lateral decubitus", "supine position"). We applied appropriate Boolean operators to broaden the query. The search was limited to human studies published in the English language. This comprehensive strategy was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, and duplicate records were removed before screening (Fig. 1).

Screening

Following the removal of duplicates, 3801 records remained. These records were screened based on titles and abstracts. Studies that did not specifically address the impact of surgical positioning on the anatomical or clinical outcomes of interest were excluded. After this phase, 382 studies were selected for full-text review.

Eligibility

We included original quantitative studies—randomised, quasi-experimental, or observational—that (1) compared at least two of the three index positions (prone, supine, lateral) in adult spine surgery and (2) reported numeric data on vascular displacement, retroperitoneal organ shift, psoas/nerve plexus position, or segmental lordosis measured in millimetres or degrees. Case reports, cadaveric studies, conference abstracts, and reviews were excluded from the analysis.

After automatic duplicate removal, 290 records remained for title/abstract screening in Rayyan. Two reviewers (A.D. and S.S.) independently screened all titles and abstracts/abstracts and subsequently the full texts of 50 articles; Cohen's κ for inclusion agreement was 0.88. Discrepancies were resolved by consensus or third-reviewer arbitration (F.M.).

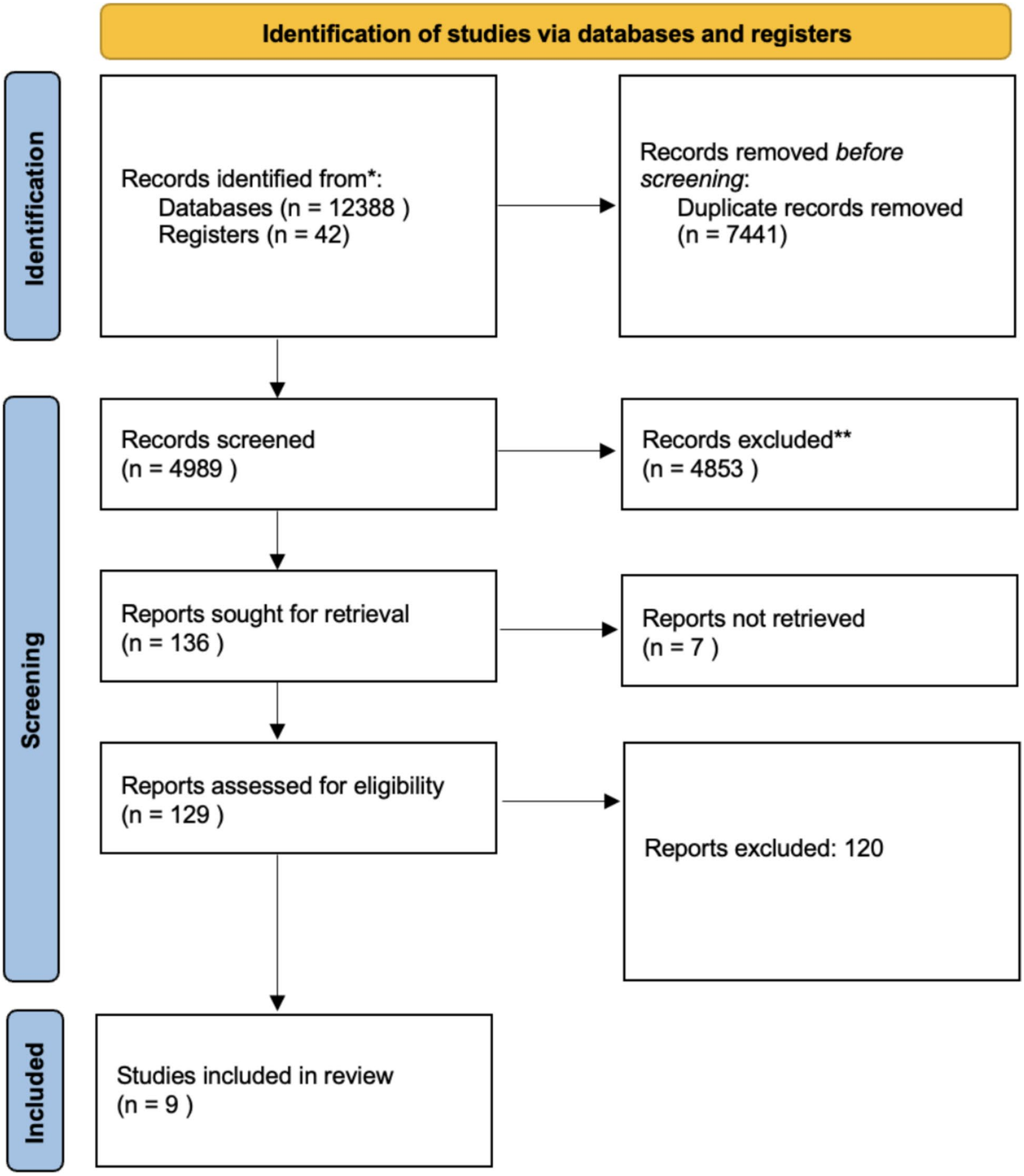

Fig. 1 PRISMA 2020 flow diagram for the literature search and study selection

Data extraction

A piloted data-extraction form (Microsoft Excel) captured:

- Bibliographic details (first author, year, country)
- Study design and sample size
- Index and reference positions (e.g., "supine → prone")
- Spinal level(s), structure examined (aorta, IVC, colon, psoas, lordosis)

- Imaging modality (CT, MRI, fluoroscopy, ultrasound, intra-operative radiograph)
- Means, standard deviations (SD), and *n* for each position.

All extractions were performed in duplicate (A.D., S.S.); conflicts were reconciled by discussion. Where data were reported graphically, means and SD were digitised using WebPlotDigitizer 4.6. To ensure consistency across the extracted data, the authors utilised a standardised data extraction form. This form was designed to capture all relevant details consistently across different studies, ensuring that no critical information was overlooked. The form included predefined fields for each variable, and each author independently filled out the form based on their review of the study data. After the initial extraction, the two sets of data were compared, and any discrepancies were resolved through discussion and consensus. This rigorous approach minimised the risk of errors and ensured that the extracted data were reliable and comprehensive.

Studies that lacked quantitative outcomes, did not specify the surgical position, or were reviews/commentaries were excluded. Following this evaluation, 240 studies were excluded due to reasons such as the lack of relevant data or failure to meet the eligibility criteria.

Inclusion

A total of nine studies were included in the meta-analysis. These studies provided data on the impact of prone, supine, and lateral positions on vascular displacement, abdominal content migration, and changes in lumbar lordosis.

Risk-of-bias assessment

Because all included studies were non-randomised, ROBINS-I was applied to seven bias domains (confounding, selection, classification, deviation, missing data, measurement, reporting). Each study was independently rated as low, moderate, serious, or critical risk by two reviewers; M.K. adjudicated disagreements. The risk profile informed sensitivity analyses and the narrative interpretation.

Statistical methods

The analyses described in this study were performed using the R programming language. The meta and metafor packages were used to conduct the traditional meta-analysis, including the leave-one-out sensitivity analysis. For the Bayesian meta-analysis, the rstanarm package was utilised. This package enables Bayesian modelling using the Stan probabilistic programming language, which is integrated within R. The rstanarm package simplifies the process of fitting Bayesian models, allowing researchers to specify models using familiar R syntax while leveraging the power of Stan for MCMC sampling.

To synthesise all direct and indirect evidence across the three index positions, we ran a frequentist graph-theoretical NMA with the netmeta R package (v 1.5– 2). Treatment effects were expressed as mean differences (MD) and estimated under a common-effects model and a random-effects model using the restricted maximum-likelihood (REML)estimator for τ2τ2. Global heterogeneity was quantified using QQ and I2I2; incoherence between multi-arm designs and the network as a whole was assessed with the design-by-treatment interaction test.

A leave-one-out sensitivity analysis was performed to assess the robustness of the pooled effect sizes. Forest plots were generated to visualise the effect sizes with and without each study, providing clear insights into the stability of the findings. The I^2 statistic was recalculated for each iteration to monitor changes in heterogeneity. The Bayesian meta-analysis was conducted using the Markov Chain Monte Carlo (MCMC) methods to estimate the posterior distributions of the mean effect size and residual standard deviation. Four independent Markov chains of 2000 iterations each (500-iterations warm-up, 1500 samples retained; total posterior draws = 6000) were run in *rstanarm 2.21*. Convergence was confirmed for all monitored parameters (R-hat ≤ 1.01; adequate sample size > 1000). A weakly informative prior Normal(0, 100) on the pooled mean and a *half-Cauchy*(0,10) on τ were chosen to let the data dominate while avoiding improper posteriors. The 95% credible intervals provided a clear indication of the uncertainty surrounding the estimates, and the posterior distributions were examined to assess the likelihood of various effect sizes.

Results

Study selection and characteristics

The search yielded 12,388 records, of which 4989 titles and abstracts were screened after duplicate removal, 129 full texts were examined, and nine studies containing 41 independent comparisons met all eligibility criteria (PRISMA flow diagram, Fig. 1). Half of the outcome assessments were performed using MRI (49%), the remainder employed CT (34%), ultrasound (10%), or intraoperative fluoroscopy (7%). Vascular displacement accounted for 18 comparisons, retroperitoneal-organ shift for 7, psoas/plexus position for 6, and segmental lordosis for 10. Detailed study-level information, including spinal level, structure examined and imaging modality, is provided in Supplement 1.

Risk of bias and sensitivity analysis

Among the nine contributing studies, two were judged at low overall risk of bias, three at moderate, three at serious and one at critical risk (Table 1). Most concerns arose from confounding by patient selection and unblinded outcome measurement; nevertheless, exclusion of serious/critical studies did not materially change the pooled estimate.

The leave-one-out influence analysis showed that the pooled MD varied only from + 2.02 mm/° to + 2.81 mm/° across 41 re-fits—well within the original 95% confidence limits. Corresponding τ^2 estimates ranged from 25.2 mm^2 to 39.4 mm^2 (Fig. 2).

Re-estimating between-study variance with DerSimonian–Laird or Paule–Mandel methods, and re-running the Bayesian model with a half-Cauchy (0, 10) prior, changed the pooled MD by < 0.4 mm/° and did not affect statistical significance.

Overall pooled effect and heterogeneity analysis

Across all anatomical structures and position pairs, the random-effects meta-analysis produced a mean difference (MD) of + 2.50 mm or degrees (95% CI 0.20–4.79; $p = 0.034$). Between-study heterogeneity was very high ($\tau^2 = 37.7$; $I^2 = 99.97\%$), and the 95% prediction interval ranged from −9.7 to + 14.7 mm/°.

Meta-regression

A mixed-effects model that included comparison position, imaging modality, and anatomical domain

Table 1 ROBINS-I traffic-light matrix showing domain-level and overall risk-of-bias judgements for the nine included studies. Colours: green = low risk, yellow = moderate, orange = serious, red = critical, grey = not applicable

Study	Conf.	Sel.	Class.	Dev.	Miss.	Outcome	Report	Overall
Smith 2021	Low	Low	Low	Low	Low	Low	Low	Low
Dodo 2023	Serious	Moderate	Low	Low	Low	Moderate	Low	Serious
Menezes 202	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Farber 2025	Serious	Moderate	Low	Low	Low	Low	Moderate	Serious
Gandhi 2022	Serious	Serious	Low	NA	Low	Serious	Serious	Serious
Mandelli 201	Critical	Serious	Low	Low	Low	Low	Low	Critical
Hiyama 2019	Moderate	Low	Low	Low	Low	Low	Low	Low
Amaral 2021	Moderate	Moderate	Moderate	Low	Low	Moderate	Low	Moderate
Pimenta 202	Serious	Moderate	Low	Moderate	Low	Low	Low	Serious

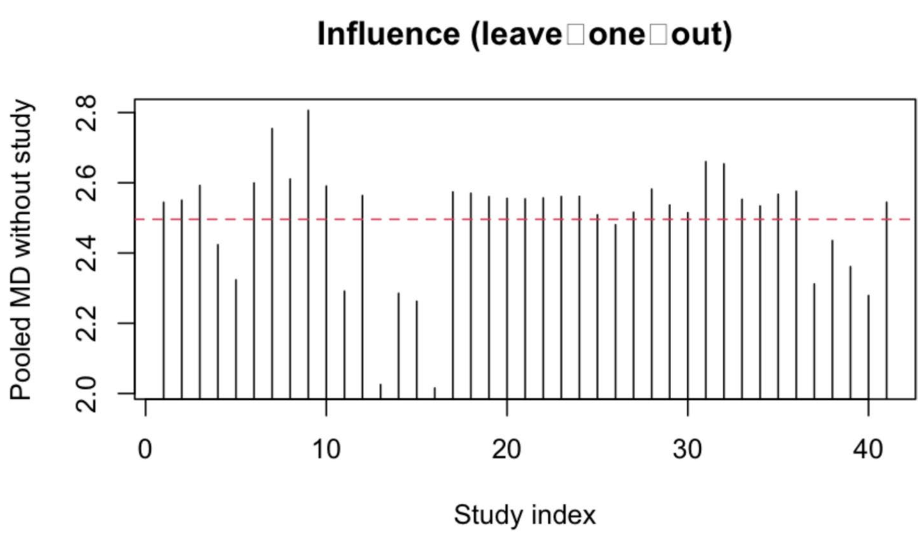

Fig. 2 Leave-one-out influence analysis of the pooled mean difference (MD). Each vertical bar shows the pooled MD after omitting one comparison; the dashed red line marks the overall random-effects estimate (+ 2.50 mm/°). None of the 41 deletions moved the pooled effect outside the original 95% CI, confirming the robustness of the result

explained only 2.6% of the between-study heterogeneity ($R^2 = 2.56\%$). The omnibus moderator test was non-significant (QM(6) = 5.51; $p = 0.48$; QE(34) = 251.47; $p < 0.001$), and none of the six individual coefficients reached statistical significance (see Supplementary Table S4 for full coefficients and 95% CIs).

Bayesian analysis

The Bayesian -normal random-effects model converged (all R-hat ≤ 1.01); posterior mean MD = +2.8 mm/°, 95% CrI −2.7 to + 8.4 with a posterior between-study SD of τ = 5.9 mm/° (95% CrI 2.3–12.4). Model fit and predictive performance were adequate (elpd < sub > loo < / sub > = −222.9 ± 41.7;p < sub > loo < /sub > = 30.4 ± 6.7; LOOIC = 445.7 ± 83.5). All 41 Pareto-k diagnostics were < 0.7, indicating reliable leave-one-out importance weights.

Table 2 Domain-specific random-effects meta-analysis. Pooled mean differences (MD) with 95% confidence intervals (CI) are presented for each anatomical domain; *k* = number of independent comparisons; positive MD indicates greater displacement (mm) or lordotic gain (°) in the reference position. I^2 quantifies residual heterogeneity within each subgroup

Domain	*k*	Pooled MD	95% CI	*p*-value	I^2
Retroperitoneal	7	+ 6.34 mm	1.87–10.80	0.007	84%
Vascular structures	18	+ 1.26 mm	− 2.43–4.94	0.49	93%
Psoas/plexus	6	+ 0.94 m	− 3.58–5.46	0.68	88%
Segmental lordosis	10	+ 1.55	− 4.62–7.73	0.61	91%

Results syntheses

Grouping the 41 comparisons by anatomical domain revealed that only retroperitoneal organs demonstrated a statistically significant pooled displacement (MD + 6.34 mm, 95% CI 1.87–10.80; $p = 0.007$) in the lateral decubitus to prone position. Vascular structures (+ 1.26 mm, 95% CI −2.43–4.94; $p = 0.49$), psoas/plexus position (+ 0.94 mm, 95% CI –3.58–5.46; $p = 0.68$) and segmental lordosis (+ 1.55°, 95% CI −4.62–7.73°; $p = 0.61$) were not different from zero. Full statistics, including heterogeneity, appear in Table 2, and the domain-specific forest plots are displayed in Fig. 3 A–D.

Pairwise position contrasts

Mixed-effects modelling of the three direct position contrasts revealed that the transition from supine to prone

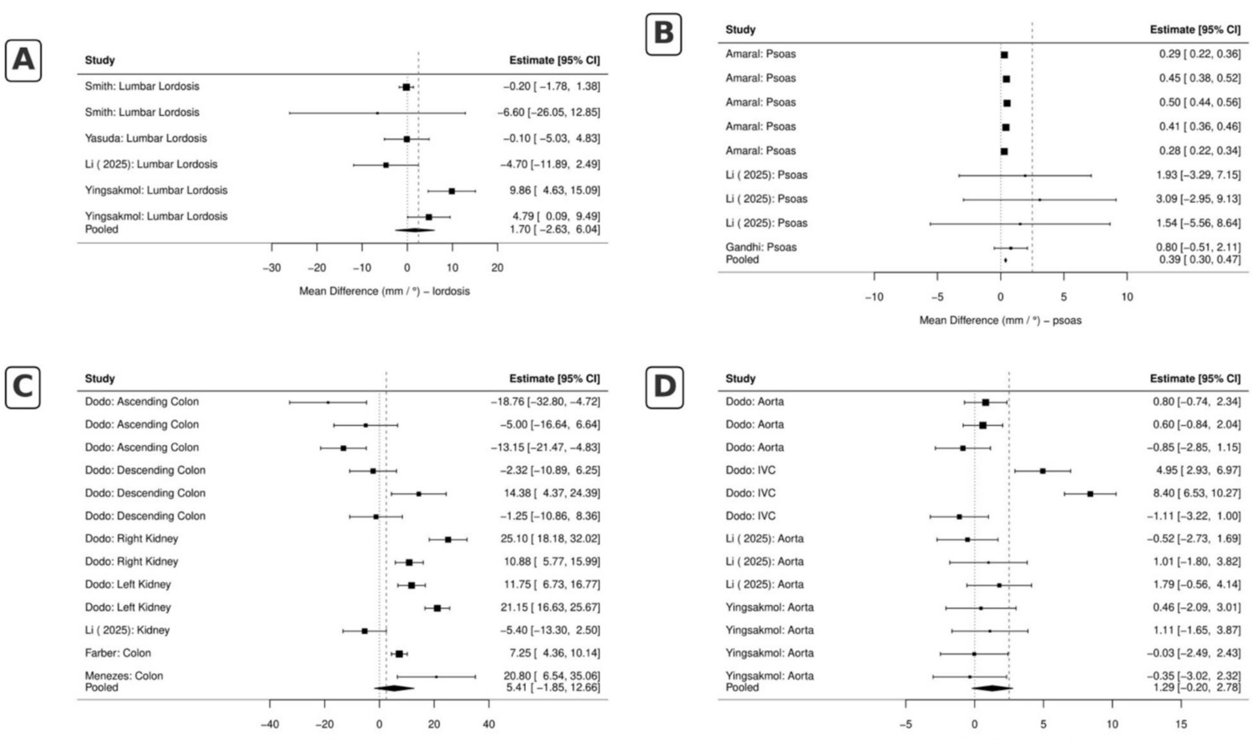

Fig. 3 Domain-specific random-effects meta-analyses. A Vascular displacement (18 comparisons); B retroperitoneal-organ shift (7 comparisons); C psoas or lumbar plexus position (6 comparisons); D segmental lordosis (10 comparisons). Grey squares represent study-level mean differences (MD) with size proportional to inverse variance; horizontal lines denote 95% confidence intervals; diamonds show pooled MD (Hartung–Knapp method). Positive values indicate anterior or lateral displacement (in millimetres) or an increase in lordosis (in degrees)

produced a significant increase in displacement or lordosis (MD + 3.64 mm/°, 95% CI 0.53–6.76; $p = 0.023$). Neither supine → lateral nor prone → lateral contrasts reached significance.

Network meta-analysis

In the random-effects model, mean differences (MD) relative to the lateral position were prone –0.16 mm/° (95% CI –3.38 to + 3.06; $p = 0.92$) and supine + 3.01 m m/° (95% CI –0.43 to + 6.44; $p = 0.086$). The indirect contrast between prone and supine was –3.17 mm/° (95% CI –6.54 to + 0.20). Global heterogeneity remained high ($\tau^2 = 37.50$; $I^2 = 89.1\%$), and significant inconsistency was detected (Q < sub > between < /sub > = 24.6, df = 1, $p < 0.0001$).

Discussion

This meta-analysis of 9 studies (41 comparisons) demonstrates that patient positioning alters spinal surgical anatomy selectively rather than uniformly. Two findings are consistent and clinically actionable: retroperitoneal organs shift posteriorly by 6 mm from the lateral to the prone position, and moving from supine to prone increases combined displacement/lordosis by 3–4 mm/°.

All other pooled effects—vascular, psoas/plexus, segmental lordosis—were small and highly variable, as reflected by an overall prediction interval of −9.7 to + 14.7 mm/°.

Robustness and uncertainty were explored systematically. Leave-one-out influence analysis confirmed that no single comparison shifted the pooled estimate outside its original 95% CI, indicating that any outlier study did not drive the findings. Meta-regression incorporating position pair, imaging modality, and anatomical domain explained only 2.6% of between-study variance, and none of the individual moderators reached significance. Hence, the high heterogeneity ($I^2 \approx 100\%$) remains unexplained mainly at the study level. Risk-of-bias stratification showed one-third of studies at serious/critical risk, yet omitting them changed the pooled MD by < 0.4 mm/° and left directionality unchanged, supporting the stability of the central conclusions despite methodological limitations.

Mean vessel displacement did not differ statistically among prone, supine and lateral positions. A thorough understanding of the vascular anatomy is imperative before surgery, as the risk is particularly heightened for less experienced surgeons, who may be more likely to inadvertently injure the inferior vena cava (IVC), given that individual patients still exhibit vessel migrations of up to one centimetre. Although the absolute excursions are small, even a 3–5 mm medial shift of the IVC can propagate distally along the common trunk and produce a comparable medialisation of the internal iliac veins at L5–S1, potentially narrowing the anterior corridor for cage insertion or screw placement at the lumbosacral junction. Gandhi et al. showed that posture changes can shift the aorta and inferior vena cava by only a few millimetres in either approach: in the lateral decubitus (with hip flexion), the aorta moved slightly lateral toward the approach side, while in prone, the aorta remained more central and the IVC shifted slightly medial [50]. Importantly, these authors noted that the calibre of the IVC changed with positioning—it appeared more engorged ("full and open") in the lateral decubitus orientation. It became flattened in supine or prone positions due to compression by abdominal contents. A compressed vein may present a smaller profile, but it does not vanish from the operative field, and the aorta's position remains relatively fixed by its tethering [49]. No clinical study to date has demonstrated a significantly lower incidence of vascular injury with prone LLIF versus traditional lateral LLIF, which aligns with the anatomical observations above. Notably, large surveys of standard lateral transpsoas fusion have documented extremely low rates of catastrophic vascular or visceral injuries—on the order of 0.1% or less for major vessel laceration and ~ 0.08% for bowel injury [27, 51]. The use of patient-specific preoperative planning, including 3D modelling or CT scans in the lateral decubitus position, may help to anticipate potential complications and tailor the surgical approach to the individual patient's anatomy [10, 52–56]. An intraoperative CT in the lateral decubitus position could provide a clearer understanding of these anatomical shifts [35, 57, 58]. Combined with navigated instrumentation, this method can address these anatomical changes, significantly reducing the risk of nerve and venous injuries while also shortening operative time (through a simultaneous dorsal approach) and enhancing overall surgical safety and efficacy [32, 59, 60]. Additionally, the use of neuromonitoring can provide valuable feedback on the status of neural structures, helping to prevent nerve damage and other neurological complications [61–66].

This study reveals a 6 mm posterior migration of the colon and kidney, which narrows the surgical corridor during anterior or anterolateral approaches at L2–L4. Nevertheless, clinically minimal displacement of abdominal contents in the supine position reaffirms its status as the preferred position for anterior spinal procedures. This interpretation is consistent with recent anatomical studies, which show that abdominal contents do not fall away substantially more in prone positioning than in the lateral decubitus orientation [67].

Dodo et al. observed that prone positioning caused a modest ventral shift of specific organs compared to supine imaging. However, a considerable proportion of patients (up to 88.6%) still had retroperitoneal structures within 10 mm of the disc space even when [68]. Similarly, Farber et al. reported that the overall magnitude of bowel migration was small and not significantly different between prone-extension and lateral decubitus positions [67]. Conventional lateral decubitus positioning with table flexion is already known to shift abdominal organs anteriorly and enlarge the retroperitoneal working space [69]. In a prospective CT study, Ouchida et al. demonstrated that lateral positioning significantly decreased the presence of organs within the operative "approach zone" compared to supine imaging [69]. However, even with the patient in the lateral decubitus position, 83% of upper lumbar levels still had the kidney overlapping the surgical corridor, and 20% had the descending colon encroaching on the disk space [69]. Menezes et al. measured a pronounced posterior migration of the intra-abdominal contents at the L4–L5 level in prone patients, which effectively halved the safe distance between the colon and the disc [70]. All subjects in their MRI series exhibited a posterior colon shift when placed in the prone position, indicating a uniform trend that potentially narrows the working window at L4–L5 [70]. These results raise concern that, without meticulous retraction and localisation, the risk of bowel contact or injury may be higher at the L4–L5 level during prone lateral fusion than in the standard lateral position. However, the supine position also presents certain limitations, particularly in terms of accessing the retroperitoneal space. The abdominal contents, including the intestines and peritoneum, lie directly over the operative site, complicating their mobilisation and increasing the risk of complications such as bowel injury or postoperative ileus if not handled meticulously. Although the supine position is well-suited for anterior lumbar interbody fusion (ALIF), it may necessitate adjunctive techniques to achieve optimal surgical outcomes when posterior access is required, demanding careful planning and execution to balance the anatomical constraints [12, 27, 71].

Prone positioning remains advantageous for sagittal realignment, as shown in this study; the statistically significant 3–4° lordosis gain can reduce the need for aggressive osteotomies. This postural advantage was anticipated: placing the patient prone naturally increases lumbar lordosis by allowing the abdomen to sag and the lumbar spine to extend. Smith et al. quantified this effect in healthy adults and found that all prone configurations yielded greater lumbar lordosis than the lateral decubitus position on a standard table [72]. In their fluoroscopic analysis, the lateral decubitus position (even with table break) produced the least lordosis. In contrast, prone positioning, especially with hips extended and gentle downward pressure or table extension, is associated with the greatest lordosis [72]. This innate increase in lordotic alignment translates into real surgical benefits when inserting interbody cages. Pimenta et al. reported that the prone transpsoas technique achieved a mean increase of ~6° in segmental lordosis at the indexed levels, significantly higher than the preoperative baseline and resulting in improved global alignment [73]. By comparison, traditional lateral decubitus LLIF typically yields about 3–4° of segmental lordotic gain per level with lordotic cages [73]. Thus, prone positioning roughly doubles the segmental correction potential relative to the same procedure performed in lateral decubitus. In Pimenta's series, this translated to better overall sagittal profiles: the proportion of patients with a high pelvic incidence–lumbar lordosis mismatch (>10°) was reduced from 22% preoperatively to 12% postoperatively with prone LLIF, representing a significant improvement in spinopelvic alignment [73]. These outcomes are comparable to, or even exceed, the lordotic corrections reported for anterior lumbar interbody fusion (ALIF) in some studies. Ahlquist et al. found that lateral interbody fusion and ALIF both produce superior radiographic lordosis gains compared to posterior fusions, with single-level LLIF improving the segmental angle by ~4.4° on average and ALIF by ~7.9° [74]. The prone lateral approach appears to bridge some of this gap by allowing a lateral cage to achieve a lordotic correction closer to that of ALIF, likely because the disc space is oriented in a more extended posture during cage insertion. Additionally, prone positioning may facilitate better access and cage placement at the L4–L5 level. Prior analyses have noted that the iliac crest can impede the trajectory for L4–L5 in lateral decubitus, sometimes necessitating table flexion or partial osteotomy of the crest [72]. In the prone position, however, the use of an adjustable frame that permits slight coronal bending of the patient can improve the L4–L5 accessibility around the iliac crest, while simultaneously capitalising on gravity to increase lordosis [72]. This dual benefit is unique to the prone lateral technique. It may be especially advantageous in patients requiring maximal lordotic restoration at L4–L5 as part of a deformity correction or to achieve global alignment.

The findings of this meta-analysis have significant implications for current surgical practices. Surgeons must account for the anatomical shifts associated with each patient position and select the most suitable strategy based on the surgery's objectives and the patient's specific anatomy. For instance, in procedures where spinal alignment is a primary goal, the prone position's ability to enhance lordosis provides a critical advantage. Combining anterior and posterior access simultaneously, while leveraging gravity, makes this approach particularly appealing for complex realignment procedures such as

Schwab osteotomies, as it eliminates the need for repositioning during surgery. It is essential to recognise that the anatomy of the psoas muscle in the prone position is likely similar to that in the supine position.

Additionally, when the abdomen is allowed to hang freely due to gravity, using proper positioning aids such as bolsters or specialised surgical tables, the abdominal contents naturally shift downward, creating a comparable retroperitoneal space for retractor placement. Future MRI studies in the prone position, with the abdomen hanging and the chest and pelvis supported on bolsters, could help validate this hypothesis by providing clearer insights into these anatomical dynamics. However, this approach is limited by anatomical structures such as the ribs and iliac crest, which can complicate access to levels like L4/5 or above L2/3.

Conversely, for surgeries requiring stability and minimal interference with abdominal contents, the supine position offers several advantages. It allows for optimal visualisation of the surgical field, including vascular, intra-abdominal, and retroperitoneal structures, making it ideal for managing complications and ensuring precise control throughout the procedure. A significant drawback lies in the influence of gravity, as abdominal structures are forced against the retractors, requiring extended effort to counteract this pressure. Furthermore, the inability to perform a simultaneous posterior approach introduces constraints, particularly in addressing severe spinal misalignments, limiting the surgeon's capacity for comprehensive correction.

Strengths of the study include the largest dataset to date, risk-of-bias stratification, and concordant findings across frequentist, network and Bayesian models. Limitations are persistent heterogeneity and an observational study design. While the meta-analysis focused on immediate anatomical changes during surgery, it does not provide information on the long-term impact of these positional changes on patient outcomes, such as recovery time, pain levels, and the need for revision surgery [18]. Future studies should address this gap by including long-term follow-up data to assess the durability of the surgical outcomes associated with different positions.

Prospective imaging studies that scan patients in all three positions, correlation of anatomical shifts with operative metrics and outcomes, and development of torque-responsive operating tables and soft-tissue-aware navigation are priority areas.

Conclusion

This meta-analysis highlights the critical impact of surgical positioning on outcomes in spine surgery. The prone position enhances spinal realignment and improves lateral retractor placement. In contrast, the supine position offers stability and alignment with standard imaging techniques, albeit with limitations on combined anterior–posterior approaches. The lateral position remains ideal for specific procedures but requires careful vascular management. Advancing imaging and positioning techniques will be key to further optimising surgical outcomes.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40001-025-03239-2.

Supplementary material 1.

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Registration and protocol
The present study was not registered.

Author contributions
FM: conception and design, statistical analysis, drafting (original and revision); SS: supervision, drafting (original), study selection and data extraction; MK, KK, RS: drafting (original); AD: literature search, study selection and data extraction, risk of bias assessment. All authors have agreed to the final version to be published.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethical approval and consent to participate
This study complies with ethical standards.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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