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LITERATURE REVIEW

Spine Surgical Subspecialty and Its Effect on Patient Outcomes

A Systematic Review and Meta-Analysis

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Study Design. Systematic review and meta-analysis.

Objective. To perform a systematic review and meta-analysis to identify if intraoperative or postoperative differences in outcomes exist between orthopedic and neurological spine surgeons.

Summary of Background Data. Spine surgeons may become board certified through orthopedic surgery or neurosurgical residency training, and recent literature has compared surgical outcomes between surgeons based on residency training background with conflicting results.

Materials and Methods. Using Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines, a search of PubMed and Scopus databases was conducted and included articles comparing outcomes between orthopedic spine surgeons and neurosurgeons. The Newcastle-Ottawa scale was used to determine the quality of studies. Forest plots were generated using mean differences (MD) for continuous variables and odds ratios (OR) for binomial variables, and 95% CI was reported.

Results. Of 615 search term results, 16 studies were identified for inclusion. Evaluation of the studies found no differences in readmission rates [OR, ref: orthopedics: 0.99 (95% CI: 0.901, 1.09); I^2 = 80%], overall complication rates [OR, ref: orthopedics: 1.03 (95% CI: 0.97, 1.10); I^2 = 70%], reoperation rates [OR, ref: orthopedics: 0.91 (95% CI: 0.82, 1.00); I^2 = 86%], or overall length of hospital stay between orthopedic spine surgeons and neurosurgeons [MD: −0.19 days (95% CI: −0.38, 0.00); I^2 = 98%]. However, neurosurgeons ordered a significantly lower rate of postoperative blood transfusions [OR, ref: orthopedics: 0.49 (95% CI: 0.41, 0.57); I^2 = 75%] while orthopedic spine surgeons had shorter operative times [MD: 14.28 minutes, (95% CI: 8.07, 20.49), I^2 = 97%].

Conclusions. Although there is significant data heterogeneity, our meta-analysis found that neurosurgeons and orthopedic spine surgeons have similar readmission, complication, and reoperation rates regardless of the type of spine surgery performed.

Key Words: comparative effectiveness research, complications, neurosurgeon, orthopedic spine surgeon, readmissions, reoperations

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Although orthopedic surgeons and neurosurgeons have different training backgrounds, both receive substantial spine-specific training.[1,2] Unfortunately, under the guise of "comparative effectiveness research", biased studies have circulated regarding the superiority of one subspecialty over the other, antagonizing the valuable collaboration between orthopedic and neurological spine surgeons.[3–5]

Both orthopedic and neurological spine surgeons have valuable insights and the clinical acumen necessary to provide high-quality patient care. Collaboration is important to improve patient care and research efforts should be focused on improving clinical outcomes rather than proving subspecialty superiority. The importance of collaboration in spine surgeon training programs is magnified and surgical trainees may benefit by becoming more well-rounded surgeons if they are under the tutelage of both orthopedic spine surgeons and neurosurgeons.[6] Although each spine subspecialty may have nuanced differences in how they provide surgical care to patients, numerous studies have demonstrated similar postoperative outcomes and cost of care across a wide range of spine surgical procedures, irrespective of training background.[7–11] In fact, one of these

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studies has even highlighted the benefits of collaboration, which illustrated lower complication rates compared with the complication rates found in the National Surgical Quality Improvement Program (NSQIP) database.[12]

The majority of studies comparing orthopedic spine and neurosurgeon postoperative outcomes have relied on mining "big data". However, these large databases are inherently flawed due to their lack of granularity, high risk for confounding, recording bias, and incomplete data.[13,14] Perhaps the largest flaw in comparing surgeon-specific risk factors is the lack of surgeon-specific variables (surgeon volume and surgeon experience level) provided by these databases, which highly correlate with patient outcomes.[15–17] Therefore, the purpose of this study is to perform a systematic review and meta-analysis of the available literature, which compares differences in postoperative outcomes based on spine surgical subspecialty.

MATERIALS AND METHODS

Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a search of PubMed and Scopus databases was conducted for studies evaluating clinical outcomes of spinal procedures based on specialty training up to February 2022.[18] Search terms included: (orthopedic) AND (neurosurgery) AND (training) AND ((specialty) OR (experience) OR (residency)) AND (outcomes). Each study's reference list was reviewed to identify eligible studies that may have been missed.

Study Selection

After title and abstract screening, full texts of selected articles were reviewed for a final decision regarding study inclusion. We included studies that directly compared outcomes between patients undergoing spinal surgery based on surgeon type: neurosurgeon versus orthopedic spine surgeon. We excluded studies that did not include postoperative outcomes or did not directly compare subspecialists. As all studies were retrospective, the Newcastle-Ottawa scale was utilized to determine study quality (Table 1).[27] Adequate follow-up was defined as 90 days or more, and a score of 7 or more indicated "quality".[28]

Statistical Analyses

Meta-analyses were performed to compare overall complications, hospital readmissions, reoperation, length of stay (LOS), operative time, and blood transfusion between neurosurgery and orthopedic surgery. Studies that reported on subgroups (procedure type or a number of levels fused) were input as separate studies. Forest plots were generated using mean differences (MD) for continuous variables and odds ratios (OR) for binomial variables, and 95% CI was reported. Study heterogeneity was reported using the I^2 statistic and funnel plots were generated for each outcome. Studies in forest plots and funnel plots were labeled numerically (Table 2). Subsequent meta-analyses were performed after the exclusion of two studies (4 subgroups) with significant heterogeneity when appropriate.[3,4] All statistical analyses were performed using *R* Studio (Version 3.6.3, Vienna, Austria).

RESULTS

Of 615 search results, 49 studies were selected for full-text review. Of these 49 studies, 14 met the inclusion criteria. Upon reviewing the reference lists for each included article, 2 additional studies were identified. This resulted in 16 studies (Figure 1). Seven (43.7%) studies were affiliated with only neurosurgical departments, whereas 5 (31.3%) included only orthopedic surgery departments. The remaining 4 (25.0%) studies had both neurosurgery and orthopedic surgery affiliations. Fourteen (87.5%) studies utilized registry data whereas 1 (6.25%) study utilized single-institution data. One (6.25%) study utilized both single-institution and database data. Of the 15 studies that utilized database data, 11 (73.3%) used NSQIP. Only one study had a quality assessment score of 7 or more (Table 1).

Complications

Of 10 studies that compared complications, 8 (80.0%)[8–12,20,21,25] found no difference in complication rates between subspecialties.[8–12,20–22,25,26] Mabud *et al*[22] found a lower overall complication rate for orthopedics for lumbar fusions (14.5% *vs*. 16.2%) and anterior cervical discectomy and fusion (ACDF) (9.9% *vs*. 10.5%). Myers *et al*[26] found a lower complication rate for neurosurgery (14.3% *vs*. 22.6%). Snyder *et al*[12] did not find a difference in their single-institution data analyzing posterior cervical decompression and fusion (OR, ref:neurosurgery:1.29, P = 0.11), but found a higher rate of complications for orthopedics when analyzing complications from NSQIP (OR, ref: neurosurgery:1.66, P < 0.0001). After running a meta-analysis, no differences in overall complication rates were found based on surgeon subspecialty [OR, ref: orthopedics: 1.03 (95% CI: 0.97, 1.10); I^2 = 70%] (Figure 2, Supplemental File A, Supplemental Digital Content 1, http://links.lww.com/BRS/C12).

Readmissions

Ten studies reported on readmission rates after surgery.[3,4,7,8,10,11,19,21–23] Eight did not detect differences in readmission rates.[7,8,10,11,19,21–23] Of the studies that did detect differences based on surgical subspecialty, one was a database study (NSQIP) comparing anterior lumbar interbody fusions (ALIFs) and lateral lumbar interbody fusion, which found lower readmission rates among neurosurgeons for multilevel procedures (3.9% *vs*. 6.9%, P < 0.001), but not single-level procedures (4.1% *vs*. 4.4%, P = 0.65).[3] A separate database (NSQIP) study by the same author group analyzed readmission rates for patients who underwent an ACDF. A lower rate of readmission in the neurosurgery group for single-level procedures (1.9% *vs*. 4.1%, P < 0.001), but not multilevel procedures (2.1% *vs*. 2.8%, P = 0.11) was identified.[4] However, the meta-analysis found no difference in

TABLE 1. Summary of Included Articles

Author (yr)	Journal	Author affiliation	Study design	Procedure type	Years	Quality assessment score	Neurosurgery patients	Orthopedic patients	Findings
Alomari (2021)[3]	World Neurosurgery	Neurosurgery	Database (NSQIP) propensity match	ALIF/LLIF	2015–2018	5	3861	3861	LOS: lower in neurosurgery Operative time: lower in orthopedics Reoperation: lower in neurosurgery Non-home discharge: lower in neurosurgery Unplanned readmission: lower in neurosurgery (multilevel only) Blood transfusion: lower in neurosurgery
Alomari (2022)[4]	Neurosurgery	Neurosurgery	Database (NSQIP) propensity match	ACDF	2016–2018	5	5058	5058	LOS: lower in neurosurgery Operative time: lower in orthopedics Reoperation: lower in neurosurgery Non-home discharge: lower in neurosurgery Unplanned readmission: lower in neurosurgery (single-level only) Blood transfusion: lower in neurosurgery Unplanned intubation: lower in neurosurgery (single-level only) Sepsis: lower in neurosurgery
Baek (2019)[7]	World Neurosurgery	Both	Database (Humana Commercial Database) retrospective	1 or 2-level posterior lumbar fusion	2007–2015	7	4986	5523	Wound complications: lower in orthopedics Dural tear: lower in neurosurgery Reoperation: no difference Readmissions: no difference
Bronheim (2018)[19]	World Neurosurgery	Both	Database (NSQIP) retrospective	Anterior lumbar surgery	2010–2014	6	1629	1553	LOS >5 days: no difference Wound complications: no difference Blood transfusion: no difference Readmission: no difference Reoperation: lower in orthopedics Urinary tract infection: lower in orthopedics
Chun (2018)[20]	Clinical Spine Surgery	Orthopedics	Database (CMS and ProPublica Surgeon Scorecard) retrospective	Elective spinal fusion	2011–2013	4	142,863 (total)	Overall complications: no difference	—
Esfahani (2018)[8]	World Neurosurgery	Neurosurgery	Database (NSQIP) propensity match	Lumbar discectomy	2005–2014	6	3732	3732	Reoperation: no difference Readmission: no difference Urinary tract infection: no difference Wound complications: no difference Blood transfusions: lower in neurosurgery Overall complications: no difference Non-home discharge: no difference Operative time: lower in orthopedics
Hu (2019)[21]	BMC Surgery	Both	Database (NSQIP) retrospective	Percutaneous kyphoplasty	2012–2014	4	1019	1229	Results were not controlled by matching or multivariate analysis. Overall complications: no difference Blood transfusion: lower in neurosurgery Unplanned intubation: no difference Urinary tract infection: no difference Reoperation: no difference Unplanned readmission: no difference

TABLE 1. (*Continued*)

Kim (2014)[9]	Spine	Orthopedics	Database (NSQIP) propensity match	Single-level lumbar fusion	2006–2011	6	1264	1264	Overall complications: no difference Wound complications: no difference Surgical site infection: no difference Unplanned reintubation: no difference Urinary tract infection: no difference Reoperation: no difference
Mabud (2017)[22]	Clinical Spine Surgery	Neurosurgery	Database (Marketscan) retrospective	Lumbar laminectomy, lumbar fusion, lumbar laminectomy with fusion, ACDF	2006–2010	6	99615	98697	Results were not controlled by matching or multivariate analysis. Wound infection: lower in orthopedics (lumbar laminectomy) Wound hematoma: lower in orthopedics (lumbar laminectomy, lumbar fusion) Delirium: lower in orthopedics (lumbar fusion) Chronic pain: lower in orthopedics (ACDF) Pulmonary complications: lower in orthopedics (lumbar fusion, ACDF) Neurological complications: lower in neurosurgery (lumbar laminectomy with fusion) Overall complications: lower in orthopedics (lumbar fusion, ACDF) Reoperation: lower in orthopedics (lumbar laminectomy with fusion, ACDF) Readmissions: no difference
Malik (2020)[23]	Clinical Neurology and Neurosurgery	Orthopedics	Database (Humana Administrative Claims) retrospective	Spinal metastases	2007–2017	6	683	204	Wound complications: no difference Pulmonary complications: no difference Urinary tract infection: no difference Reoperation: lower in neurosurgery Readmissions: no difference
McCutcheon (2015)[24]	Spine	Neurosurgery	Database (NSQIP) retrospective	Spinal fusion	2005–2011	4	5247	4350	Results were not controlled by matching or multivariate analysis. Operative time: lower in orthopedics Emergency operation: no difference Reoperation: no difference Blood transfusion: lower in neurosurgery Surgical site infection: no difference Wound complications: no difference Unplanned reintubation: no difference
Minhas (2014)[25]	Spine	Orthopedics	Database (NSQIP) propensity match	Single-level ACDF	2006–2012	6	1025	384	Overall complications: no difference Surgical site infection: no difference Wound complications: no difference Unplanned intubation: no difference Urinary tract infection: no difference Blood transfusion: no difference
Myers (2020)[26]	British Journal of Neurosurgery	Neurosurgery	Single-institution retrospective	Isolated spinal fracture	2012–2016	5	266	199	Results were not controlled by matching or multivariate analysis. Treated surgically: lower in neurosurgery LOS: no difference Intensive care unit admission: lower in orthopedics Non-home discharge: no difference Overall complications: lower in neurosurgery

Prabhakar (2020)[10]	Journal of Orthopedics	Orthopedics	Database (NSQIP) retrospective	ACDF	2011–2014	5	13356	4611	Results were not controlled by matching or multivariate analysis. Operative time: no difference LOS: no difference Unplanned intubation: no difference Surgical site infection: no difference Readmission: no difference Reoperation: no difference Overall complications: no difference
Seicean (2014)[11]	Spine	Neurosurgery	Database (NSQIP) propensity match	Elective procedures	2006–2012	6	17126	17126	LOS: lower in neurosurgery Blood transfusion: lower in neurosurgery Overall complications: no difference Reoperation: no difference Readmissions: no difference
Snyder (2019)[12]	Spine	Both	Single-institution retrospective Database (NSQIP) retrospective	Posterior cervical decompression and fusion	Single-institution: 2006–2016 NSQIP: 2007–2015	6	Single-institution: 683 NSQIP: 8706	Single-institution: 538 NSQIP: 2410	Results were not controlled by matching or multivariate analysis, with the exception of overall complications. Blood transfusion: lower in neurosurgery Wound complications: no difference Surgical site infection: no difference Pulmonary embolism: lower in neurosurgery (only single-institution) Deep venous thrombosis: lower in orthopedics (only NSQIP) Pneumonia: lower in orthopedics (only single-institution) Airway complications: lower in orthopedics (only single-institution) Urinary tract infection: no difference Overall complications: lower in neurosurgery (only NSQIP)

ACDF indicates anterior cervical discectomy and fusion; ALIF, nterior lumbar interbody fusion; LOS, length of stay; LLIF, lateral lumbar interbody fusion; NSQIP, National Surgical Quality Improvement Program.

TABLE 2. Legend Correlating the Numerical Score to Its Associated Study in the Funnel and Forest Plots

Number	Study; Author (yr) (Subgroup)
1	Alomari (2021) (single-level ALIF/LLIF)[3]
2	Alomari (2021) (multilevel ALIF/LLIF)[3]
3	Alomari (2022) (single-level ACDF)[4]
4	Alomari (2022) (multilevel ACDF)[4]
5	Baek (2019)[7]
6	Bronheim (2018)[19]
7	Chun (2018)[20]
8	Esfahani (2018)[8]
9	Hu (2019)[21]
10	Kim (2014)[9]
11	Mabud (2017) (lumbar lami)[22]
12	Mabud (2017) (lumbar fusion)[22]
13	Mabud (2017) (lumbar lami with fusion)[22]
14	Mabud (2017) (ACDF)[22]
15	Malik (2020)[23]
16	McCutcheon (2015)[24]
17	Minhas (2014)[25]
18	Myers (2020)[26]
19	Prabhakar (2020)[10]
20	Seicean (2014)[11]
21	Snyder (2019) (single-institution)[12]
22	Snyder (2019) (database)[12]

ACDF indicates anterior cervical discectomy and fusion; ALIF, anterior lumbar interbody fusion; LLIF, lateral lumbar interbody fusion.

readmission rates between neurosurgery and orthopedics [OR, ref: orthopedics: 0.99 (95% CI: 0.901, 1.09); $I^2 = 80\%$]. After the removal of the two studies causing the most significant heterogeneity, there was still no difference in readmission rates, but the meta-analysis had less heterogeneity [OR, ref: orthopedics: 1.07 (95% CI: 1.00, 1.14); $I^2 = 62\%$] (Figure 3, Supplemental File B, Supplemental Digital Content 2, http://links.lww.com/BRS/C13, Supplemental Digital Content 3, http://links.lww.com/BRS/C14).

Reoperation

Twelve studies reported on reoperation rates with 7[7–11,21,24] finding, no differences between groups.[3,4,8–12,19–23] Two NSQIP database studies found lower rates of returning to the operating room if the surgeon was a neurosurgeon, irrespective of procedure type: ALIF/lateral lumbar interbody fusion (single-level: 2.1% *vs.* 4.1%, $P < 0.001$; multilevel: 2.4% *vs.* 4.2%, $P = 0.002$) or an ACDF (single-level: 0.7% *vs.* 2.1%, $P < 0.001$; multilevel: 0.6% *vs.* 2.4%, $P < 0.001$).[3,4] A separate study evaluating a Humana Administrative Claims database of patients with spinal metastases found a lower reoperation rate for neurosurgical patients (17.3% *vs.* 26.5%, $P = 0.045$).[23] Orthopedics was found to have a lower reoperation rate in two studies, one was an

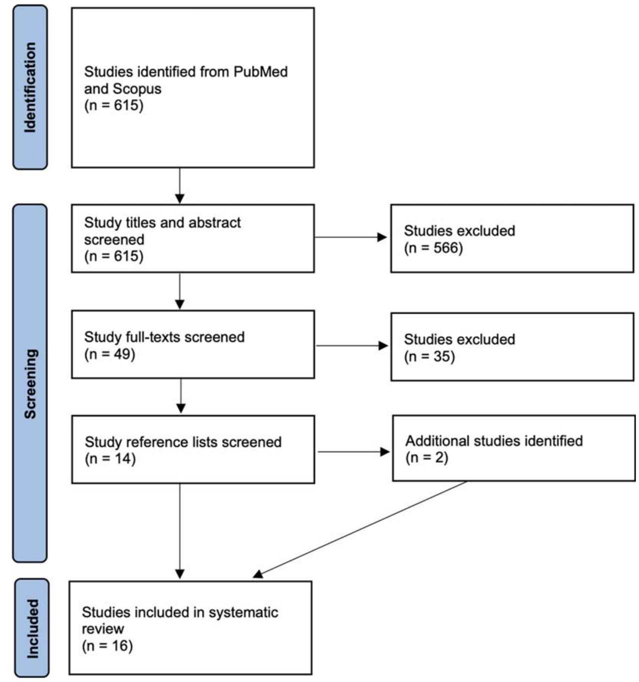

Figure 1. Preferred Reported Items for Systematic Reviews and Meta-analyses flowchart indicating the number of articles meeting inclusion and exclusion criteria. full color online

NSQIP database analyzing anterior lumber fusions and the other was a Marketscan database evaluating both lumbar laminectomy and ACDFs.[19,22] The meta-analysis of all the data found there was no difference in reoperation rates [OR, ref: orthopedics: 0.91 (95% CI: 0.82,1.00); $I^2 = 86\%$]. After the removal of the 2 most heterogeneous studies (also the studies with the lowest quality assessment), there was still no difference in reoperation rates, but less heterogeneity existed [OR, ref: orthopedics: 1.03 (95% CI: 0.96,1.12); $I^2 = 76\%$] (Figure 4, Supplemental File C, Supplemental Digital Content 4, http://links.lww.com/BRS/C15, Supplemental Digital Content 5, http://links.lww.com/BRS/C16).

Length of Stay

Six studies reported on postprocedural hospital LOS. Neurosurgeons had significantly shorter LOS in 3 studies.[3,4,11] The remaining studies found no difference in LOS.[10,19,26] The meta-analysis also found no difference in LOS [MD: –0.19 days (95% CI: –0.38, 0.00); $I^2 = 98\%$]. After the removal of the studies most influenced by heterogeneity, LOS was significantly shorter for orthopedic spine surgeons and there was less data heterogeneity [MD: 0.13 days (95% CI: 0.08, 0.18]; $I^2 = 66\%$] (Figure 5, Supplemental File D, Supplemental Digital Content 6, http://links.lww.com/BRS/C17, Supplemental Digital Content 7, http://links.lww.com/BRS/C18).

Operative Duration

The operative duration was reported in 5 studies, and 4 found orthopedics to have a shorter operative duration.[3,4,8,24] Meta-analysis demonstrated orthopedic spine surgeons had shorter operative duration when compared with neurosurgeons

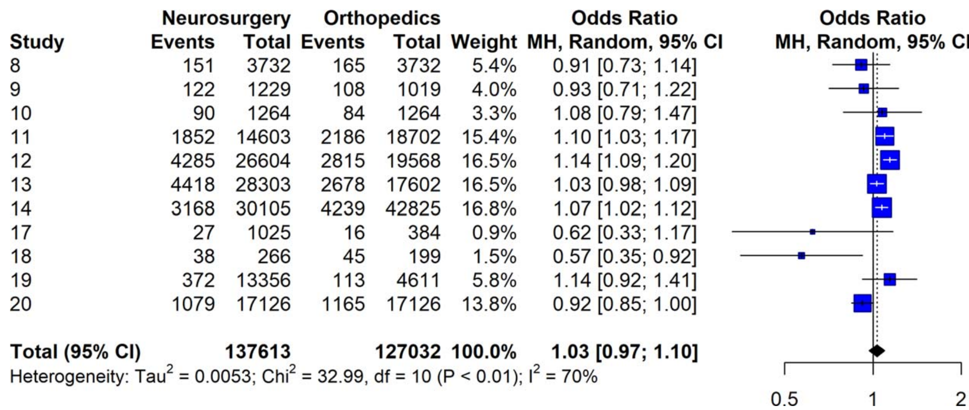

Figure 2. Forest plot indicating the weighted ORs and heterogeneity of studies comparing complication rates. MH indicates Mantel Haenszel; OR, odds ratios.

[MD: 14.28 minutes (95% CI: 8.07, 20.49), I^2 = 97%]. After the removal of the studies most influenced by heterogeneity, operative duration was significantly lower for orthopedic spine surgeons [MD: 6.44 minutes (95% CI: 2.04, 10.84); I^2 = 91%] (Supplemental Files E, Supplemental Digital Content 8, http://links.lww.com/BRS/C19, Supplemental Digital Content 9, http://links.lww.com/BRS/C20, Supplemental Files F, Supplemental Digital Content 10, http://links.lww.com/BRS/C21, Supplemental Digital Content 11, http://links.lww.com/BRS/C22.

Blood Transfusions

Nine studies compared the rates of blood transfusion, and neurosurgery was found to have lower rates of blood transfusion in 7.[3,4,8,11,12,21,24] The meta-analysis showed that neurosurgery had significantly lower blood transfusion

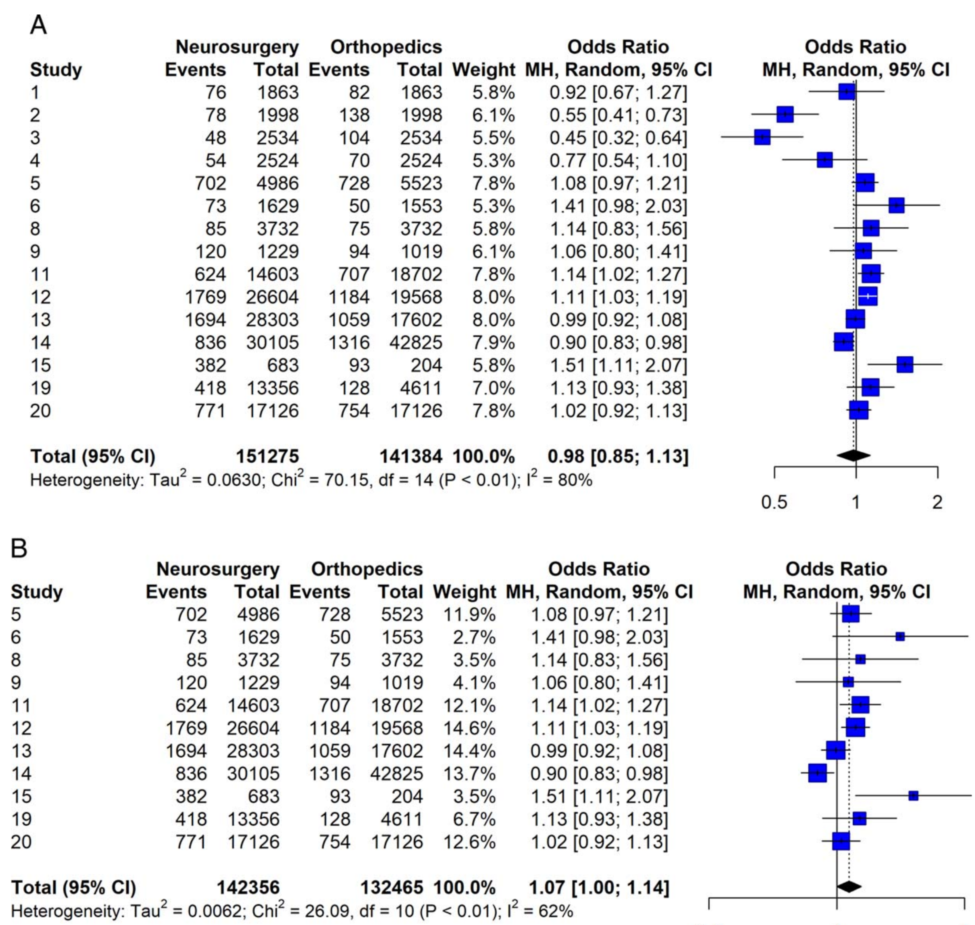

Figure 3. Forest plot indicating the weighted ORs and heterogeneity of studies comparing readmission rates for (A) all studies and (B) after exclusion of the studies causing the most heterogeneity. MH indicates Mantel Haenszel; OR, odds ratios.

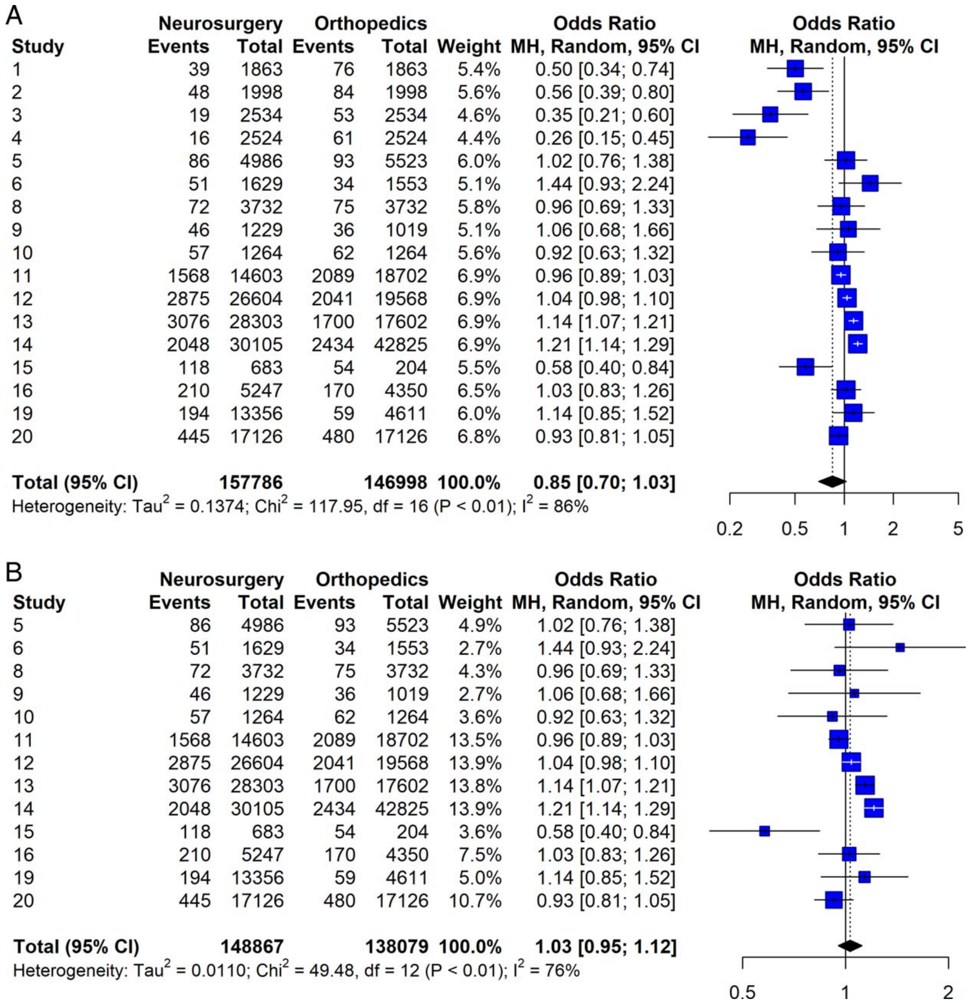

Figure 4. Forest plot indicating the weighted ORs and heterogeneity of studies comparing reoperation rates for (A) all studies and (B) after exclusion of the studies causing the most heterogeneity. MH indicates mantel Haenszel; OR, odds ratios. full color online

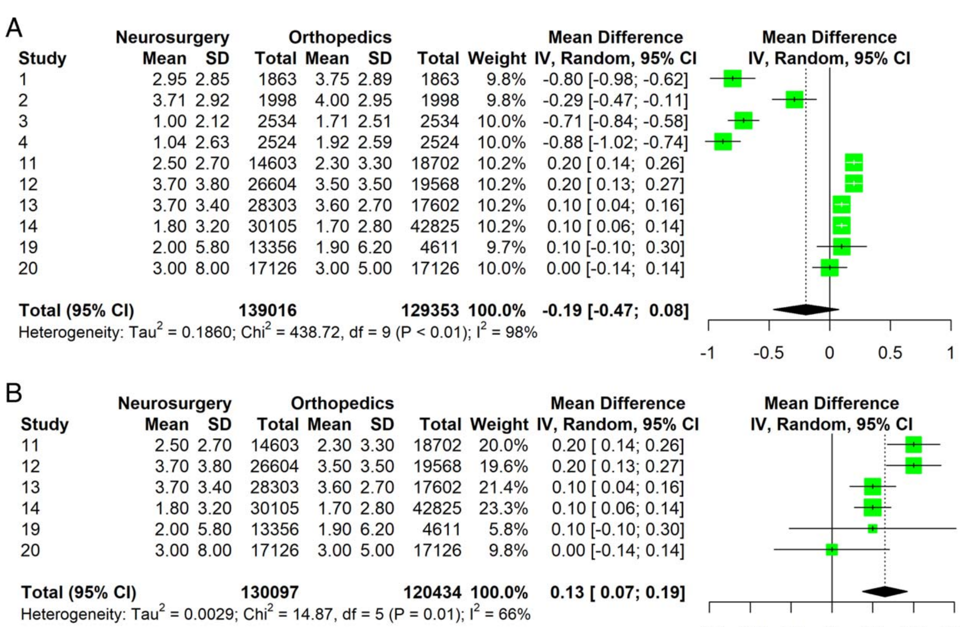

Figure 5. Forest plot indicating the weighted ORs and heterogeneity of studies comparing hospital LOS for (A) all studies and (B) after exclusion of the studies causing the most heterogeneity. LOS indicates length of stay; OR, odds ratios. full color online

rates when compared with orthopedic spine surgeons [OR, ref: orthopedics: 0.49 (95% CI: 0.41, 0.57); $I^2 = 75\%$]. After the removal of the two studies that most influenced heterogeneity, neurosurgery had a significantly lower rate of blood transfusions [OR, ref: orthopedics: 0.57 (95% CI: 0.50, 0.65); $I^2 = 61\%$] (Supplemental Files G, Supplemental Digital Content 12, http://links.lww.com/BRS/C23, Supplemental Digital Content 13, http://links.lww.com/BRS/C24, Supplemental Files H, Supplemental Digital Content 14, http://links.lww.com/BRS/C25, Supplemental Digital Content 15, http://links.lww.com/BRS/C26).

DISCUSSION

Historically, orthopedic surgery training focused on bone biology and healing, including spinal instrumentation. Neurosurgery training focused on cases involving neurological structures and intradural procedures. With fellowship cross-training, these nuances are more likely to be learned by trainees.[5] The results of our meta-analysis emphasize the lack of differences in patient outcomes between surgical subspecialties. Although minor differences exist in surgical characteristics and outcomes (neurosurgeons are less likely to order blood transfusions, but patients have a longer operative duration and hospital LOS), no differences were found for reoperation, readmission, or complication rates based on surgeon subspecialty.

It is worth noting that studies comparing orthopedic spine and neurosurgeon outcomes are inherently at risk of bias, as there is a significant financial incentive to demonstrate the superiority of one group compared with the other.[29] Therefore, critical analysis of each manuscript for appropriate unbiased statistical analysis is essential. Intuitively, the inclusion of both orthopedic spine surgeons and neurosurgeons on a manuscript will provide for appropriate vetting before publication and may mitigate the number of flawed studies passing through peer review.[3,4]

In most instances, studies with obvious publication bias are removed from a meta-analysis; however, part of the objective of this study was to include publications regardless of potential bias with the understanding that this topic may engender more disagreement among spine surgeons due to the practitioner's inherent bias and financial incentives. Unfortunately, this was not possible after analysis of the funnel plots, which indicated significant bias was present, especially from studies originating from one surgical group that published on complication and readmission rates in patients undergoing ALIFs and ACDFs.[3,4] Without the exclusion of these 2 publications, funnel plots indicated 40% of the included studies evaluating complications suffered from publication bias, compared with only 18% when those studies were excluded (similar findings were present when analyzing reoperation rates). However, it is worth mentioning that regardless of the inclusion or exclusion of the above 2 studies, our analysis demonstrated that neither complication rates nor readmission rates identified significant statistical differences in outcomes based on surgical subspecialty.[3,4]

According to previously published data from NSQIP, there is nearly a 3 times higher surgical volume of ACDFs performed by neurosurgeons, which may account for some differences in patient outcomes.[4,17] However, the cause of the greater volume of cases performed by neurosurgeons at the 700+ hospitals included in NSQIP is unclear. Although NSQIP does state that the included hospitals are a mix of academic and private practice surgeons, NSQIP neither provides which hospitals are included in the database nor do they provide a breakdown of the percentage of included patients who receive care from an academic or private practice spine surgeon. Further, there is insufficient literature to determine whether this disparity in surgical volume is reflective of national trends.

As nearly all the literature included in our meta-analysis was based on database studies, further discussion of the limitations inherent in databases is necessary. The most likely cause for unintended bias is missing data. Research indicates 5% of patients included in databases have missing demographic information and 72% have at least some missing comorbidity data.[13] As most regression analyses require a complete set of data to compute ORs, data analysis is heavily influenced based on if authors decide to exclude patients with missing information. In general, excluding patients leads to greater treatment benefits and statistical significance (lower *P* values), but this comes at the price of significant data heterogeneity.[30] Therefore, all database studies should clearly outline their criteria for patient inclusion/exclusion. Further, databases are at high risk of recording bias due to financial incentives, unintended recording inaccuracies, and improper patient matching–leading to analyses improperly controlling for confounding.[14] Recommended practice guidelines have been established for NSQIP; however, 93% of orthopedic studies between 2016 and 2017 did not adhere to these guidelines and the majority of neurosurgical studies did not sufficiently discuss potential sources of bias, data cleaning methodology, and external validity.[31,32]

When analyzing the results of our meta-analysis, the two most consistent findings were the significant reduction in blood transfusions ordered by neurosurgeons and the longer operative duration for neurosurgeons compared with orthopedic spine surgeons. Although the direct costs of transfusions are relatively low ($240.90), transfusions do carry significant indirect costs including greater rates of postsurgical infections and readmissions.[33,34] Given that longer surgical times have been linked to increased postoperative complications, a finding that was not seen in our meta-analysis, we hypothesize that longer operative times and lower transfusion rates are linked.[35–38] As neurosurgeons spend a significant portion of their training and surgical practice performing intracranial procedures, where meticulous hemostasis is critical to avoid catastrophic outcomes including death, they may spend more time limiting blood loss during spine procedures. This may manifest as longer operative times and lower transfusion rates. Therefore, our meta-analysis places emphasis on 2 key points. First, adhering to established literature guidelines for blood transfusions may limit unnecessary transfusions and secondly, meticulous intraoperative hemostasis will likely limit a patient's need for blood transfusions but may increase the overall length of the procedure.

Finally, discussion on the merit of comparative effectiveness research as it pertains to outcomes warrants mentioning. This meta-analysis found surgical outcomes are likely unrelated to a surgeon's subspecialty. However, improvement in outcomes is most likely in high surgical volume practices with neurosurgeons and orthopedic surgeon collaboration.[39–42] As neurosurgeons and orthopedic spine surgeons have historically had different training backgrounds, spine patients likely stand to benefit from the unique skillsets and viewpoints that each subspecialty provides. Institutional fostering of the relationship between neurosurgeons and orthopedic spine surgeons may improve outcomes for spine patients.

Certain limitations were present based on the methodology of the meta-analysis. First, all procedure types were grouped together regardless of fusion technique or spine location, which increased heterogeneity. Although the overall complication rate is different based on surgical invasiveness, each study directly compared orthopedic spine and neurosurgeons. Further, although most database studies relied on NSQIP, the inclusion of other databases made it difficult to directly compare specific surgical complications. As a result, our study only focused on outcomes that were common among all databases, which increased the risk of information bias. Finally, although most studies rely on Newcastle-Ottawa scores or funnel plots to remove publications with a large risk of bias, this was impractical based on a large number of database studies included and the inherent heterogeneity present. As two studies disproportionately skewed the data, we chose to analyze the data twice, once with all studies included and a second time with only the 2 most biased studies excluded.[3,4] This allowed our study to maintain a large power while also demonstrating how flawed study methodology can adversely affect publication findings.

CONCLUSIONS

Neurosurgeons and orthopedic spine surgeons have different pathways before becoming dedicated spine surgeons. However, both subspecialties have similar readmission, complication, and reoperation rates across a wide variety of surgical procedures.

➢ Key Points

- ❑ Neurological and orthopedic spine surgeons did not have significant differences in readmission, complication, and reoperation rates.
- ❑ Orthopedic spine surgeons had shorter operative durations.
- ❑ Neurological spine surgeons had a lower rate of postoperative blood transfusion.

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