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Outcomes following primary total hip replacement with pre-existing spinal fusion surgery: A systematic review and meta-analysis of observational evidence

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Abstract

Aims: There is inconsistent evidence on whether prior spinal fusion surgery adversely impacts outcomes following total hip arthroplasty (THA). We conducted a systematic review and meta-analysis to assess the association between pre-existing spinal fusion surgery and the rate of complications following primary THA.

Materials and Methods: We searched MEDLINE, Embase, Web of Science, and Cochrane Library up to October 2019 for randomised controlled trials (RCTs) and observational studies comparing outcomes of dislocation, revision, or reasons for revision in patients following primary THA with or without pre-existing spinal fusion surgery. Furthermore, we compared short (2 or less levels) or long (3 or more levels) spinal fusions to no fusion. Summary measures of association were relative risks (RRs) (with 95% confidence intervals, CIs).

Results: We identified 10 articles corresponding to 9 unique observational studies comprising of 1,992,366 primary THAs. No RCTs were identified. There were 32,945 cases of spinal fusion and 1,752,362 non-cases. Comparing prior spinal fusion versus no spinal fusion in primary THA, RRs (95% CIs) for dislocation 2.23 (1.81-2.74) (7 studies), revision 2.14 (1.63-2.83) (5 studies), periprosthetic joint infection 1.71 (1.53-1.92) (4 studies), periprosthetic fracture 1.52 (1.28-1.81) (3 studies), aseptic loosening 1.76 (1.54-2.01) (3 studies), and any complications 2.82 (1.37-5.80) (3 studies) were identified. Both short or long spinal fusion when compared with no fusion were associated dislocation, revision, or reasons for revision.

Conclusions: Patients with prior spinal fusion are at risk of adverse events following primary THA. Measures that reduce the risk of these complications should be considered in this high-risk population when undergoing primary THA. These patients should also be counselled appropriately around their risks of undergoing THA.

Bullet points:

Patients with prior spinal fusion are at an increased risk of adverse events, including dislocation, aseptic loosening, peri-prosthetic fracture, infection and revision when undergoing primary THA.

Keywords Hip, spine, replacement, fusion, dislocation, revision, complication, systematic review, meta-analysis

Introduction

As patient populations age there is an increasing burden of disability from osteoarthritis of the hip and degenerative disease of the spine fuelling an ever increasing requirement for total hip arthroplasty (THA) and spinal fusion.[1,2] Independently, these two procedures carry challenges which are compounded when both hip and spine degeneration coexist. Statically, the alignment of the lumbar spine affects pelvic and therefore hip position. Commonly, this is recognised with a lumbar scoliosis causing pelvic obliquity, but similarly, sagittal spinal malalignment is partially compensated for by pelvic version.[3] Dynamically, stiffness of the lumbar spine requires compensation by the hips to achieve spinopelvic range of motion.[4] Thus, lumbar fusion, which affects the spine's alignment and range of motion, induces static and dynamic effects on the pelvis. Therefore, in patients with a lumbar fusion contemplating THA, the implications of their reduced spinal movement and position of the spine fusion needs to be understood.[5]

Of particular importance in THA, is optimising the cup's position to reduce edge loading, squeaking, impingement and dislocation. While historically, Lewinnek and Grammatopoulos [6,7] safe zones were proposed as predictive measures for hip dislocation and edge loading respectively, these measurements rely on a single standing antero-posterior (AP) pelvic radiograph and therefore fail to assess the individual's static sagittal alignment or dynamic spinopelvic motion. This may, at least in part, explain why they have shown to not adequately predict the risk of dislocation and wear. [8,9] More recently, a recognition of spinopelvic kinematics has emphasised the importance of the functional acetabular orientation [10] and the importance of spinal mobility on THA outcomes.[11,12] Yet, despite recognising these effects, the implications of previous spinal fusions and quantification of the effect on the outcomes of THA remain controversial.

Previous reports and systematic reviews of the published literature have attempted to evaluate the effects of lumbar fusion on THA. Riviere and colleagues performed a systematic review of various spinopelvic radiological parameters and found a significant relationship between these parameters on THA impingement and dislocation.[13] In 2017, An and colleagues performed a meta-analysis of the risk of lumbar fusion on THA dislocation and revision.[5] They identified 6 prior articles, all published in 2016 and 2017, illustrating the

relative novelty of the ideation that the spine has significant bearing on THA outcomes. They also identified a two-fold increased rate of dislocation and three-fold increased rate of revision in those patients who had a lumbar fusion prior to THA.[5] However, this study was limited to the English literature, and did not assess other outcomes such as aseptic loosening or periprosthetic fracture, that we have anecdotally seen to be higher in this patient population. Furthermore they did not explore the association between rates and the number of spinal levels fused.

Thus, we aimed to perform a comprehensive and generalisable assessment of adverse outcomes following primary THA in patients with or without prior spinal fusion surgery, using an updated systematic meta-analysis of published studies.

Materials and Methods

Data sources and search strategy

This review was conducted in accordance with PRISMA and MOOSE guidelines[14,15] (Supplementary Materials 1-2) and based on a pre-defined protocol in the prospective register of systematic reviews, PROSPERO (CRD42018100565). The following databases were searched from inception to 28 October 2019: MEDLINE, Embase, and The Cochrane library. The search strategy was constructed by combining MeSH search terms and key words related to the exposure (e.g., “spinal fusion”, “spinal deformity”, “spinal stenosis”) and population (e.g., “primary total hip replacement”) and it was restricted to human studies with no limits on language. Details of the MEDLINE search strategy are reported in Supplementary Material 3. Initial screening of all titles and abstracts of studies retrieved from the databases was performed by one reviewer (MCW) to assess their potential for inclusion. This was then followed by the acquisition of full texts of potentially eligible studies and detailed evaluation which was done by 2 independent reviewers (MCW and SKK). Reference lists of relevant review articles and some of the included studies were manually assessed to identify any additional papers.

Eligibility criteria

Studies were eligible if they were comparative observational cohort designs, case-control designs, or randomised controlled trials (RCTs) that: (i) recruited participants undergoing primary THA; (ii) compared pre-existing spinal fusion surgery vs none; and (ii) reported any of the following outcomes after a period of follow-up following primary THA – dislocations, revisions, reasons for revision such as mechanical loosening, periprosthetic fracture, prosthetic joint infection (PJI), and any complications. No restrictions were imposed on the follow-up duration. We excluded the following studies: (i) those with no comparison or control groups; (ii) revision THAs; (iii) those that involved only particular indications for THA such as hip fracture; and (iv) those that included only hemiarthroplasty or hip resurfacing.

Data extraction and quality assessment

One reviewer (MCW) extracted study information into a standardised data collection spreadsheet. A second reviewer (SKK) then independently checked the extracted data with that in the original papers. Data was extracted on the following: first author's name, study publication date, country and geographical location of study, study design, baseline year, mean age, duration of follow-up, sample size, outcomes, number of outcomes in each group, and risk estimates (relative risks (RRs), hazard ratios (HRs), or odds ratios (ORs)). We defined "short" spinal fusion as two or less motion segments fused and "long" spinal fusion as three of more segments fused. When the same study was described in multiple publications, the paper with the most comprehensive information was used. Methodological quality of each eligible study was assessed using the nine-star Newcastle-Ottawa Scale (NOS).[16] NOS measures the quality of non-randomised studies from a score of zero to nine, based on three pre-defined domains including: (i) selection of participants; (ii) comparability of study groups; and (iii) ascertainment of outcomes of interest.

Statistical analyses

Relative risks (RRs) with 95% confidence intervals (CIs) were used as summary measures of associations across studies. Since the outcomes evaluated (e.g., dislocation, revision, PJI) can be considered a rare complication (prevalence < 10%), reported HRs and ORs were assumed to approximate the same measure of RR following Cornfield's rare disease outcome assumption.[17] Multivariable-adjusted risk estimates were

extracted for pooling when reported, otherwise crude RRs were calculated from the extracted raw counts. Random-effects models were used to combine RRs to minimise the effect of heterogeneity.[18] Heterogeneity was assessed using the Cochrane χ^2 statistic and the I^2 statistic.[19] The statistical analyses employed STATA release 16 (Stata Corp, College Station, Texas, USA).

Results

Study identification and selection

The literature search strategy and manual screening of references lists identified 329 potentially eligible articles. After screening of titles and abstracts, 75 articles remained for detailed full text evaluation. Following evaluation, 65 articles were excluded because (i) the exposure was not relevant (n=18); (ii) were based on reviews and letters (n=14); (iii) no appropriate control group (n=10); (iv) population not relevant (n=8); (v) were duplicates of studies already included in review (n=7); (vi) outcomes were not relevant (n=6); (vii) full text could not be retrieved (n=1); (viii) based on an abstract (n=1). The remaining 10 articles corresponding to 9 unique studies were eligible to be included in the review[20-29] (**Figure 1**).

Study characteristics and quality

The majority of studies were based on retrospective cohort designs with one based on a prospective cohort and another on a retrospective case-control design. No RCTs were identified. Publication dates of included articles ranged from 2016 to 2019. Relevant baseline characteristics and quality assessment scores of the individual articles/studies are summarized in Table 1. The 9 unique studies involved 1,992,366 primary THAs. There were 32,945 cases of spinal fusion and 1,752,362 non-cases. Overall, 7 studies were conducted in North America (USA), 1 in Europe (France) and 1 in Asia (Singapore). The average baseline age of participants in the included studies ranged from 64.5 to 71.0 years and the weighted mean age was 64.5 years. The average overall duration of follow-up for outcomes ranged from 90 days to 2.7 years, with a weighted mean follow-up duration of 0.9 years. Methodological quality of observational studies ranged from 4-8 using NOS.

Spinal fusion and risk of outcomes

A total of 7 studies comprising of 1,992,251 primary THAs contributed to the pooled analysis for dislocation. There were 32,817 cases of spinal fusion and 1,752,149 non-cases. The pooled RR (95% CI) of dislocation comparing patients with prior spinal fusion versus without was 2.23 (1.81-2.74) (Figure 2). There was evidence of significant heterogeneity between contributing studies (I^2 =77%; 95% CI: 53-89%; p<0.001). One study could not be included in the pooled analysis because none of the patients in either group experienced a dislocation;[24] this study did not provide details of the follow-up period, hence it is uncertain if the zero event rate could be attributed to lack of follow-up. Five studies comprising of 649,820 primary THAs contributed to the pooled analysis for revision and these included 10,569 cases of spinal fusion and 639,251 non-cases. The corresponding pooled RR (95% CI) for revision was 2.14 (1.63-2.83) (Figure 2) with evidence of moderate heterogeneity across the studies (I^2 =53%; 95% CI: 0-83%; p=0.073). Comparing patients with prior spinal fusion to those without, the pooled RRs (95% CIs) for PJI (4 studies; 599,555 THAs; 9,909 spinal fusion and 589,646 non-cases), periprosthetic fracture (3 studies; 599,391 THAs; 9,827 spinal fusion and 589,564 non-cases), aseptic loosening (3 studies; 599,391 THAs; 9,827 spinal fusion and 589,564 non-cases), and any complications (3 studies; 649,020 THAs; 10,441 spinal fusion and 638,579 non-cases) were 1.71 (1.53-1.92), 1.52 (1.28-1.81), 1.76 (1.54-2.01), and 2.82 (1.37-5.80) respectively (Figure 3). Note that variable number of studies in the pooled analysis relates to whether the individual article reported on the outcome of interest. Results from single reports showed no significant associations of prior spinal fusion with a discharge destination other than home, readmission or hardware complication (Figure 2).

In studies that compared short spinal fusion (1 to 2-level lumbar fusion) or long spinal fusion (3 to 7-level lumbar fusion) with no spinal fusion, there was an increased risk of all outcomes evaluated (dislocation, revision, aseptic loosening, periprosthetic fracture, PJI, and any complications) (Supplementary Materials 4-5). The risk of dislocation comparing short versus long spinal fusion was based on findings from two single reports. One study reported an increased risk of dislocation when long spinal fusion was compared with short

spinal fusion RR (95% CIs) of 1.60 (1.24-2.07).[3] The other study reported no significant difference in dislocation-free survival by level of fusion when comparing short versus long spinal fusions.[27]

Discussion

This systematic meta-analysis of observational studies shows that patients with a prior spinal fusion have a substantially and significantly increased risk of dislocation, revision, aseptic loosening, periprosthetic fracture, PJI, and other adverse events following primary THA compared to those without prior spinal fusion. Furthermore, both short and long spinal fusion, when compared with no fusion, are associated with increased risk of dislocation, revision and reasons for revision.

The more than two-fold increased risk of dislocation identified in this study is consistent with that reported by An and colleagues.[5] One can postulate that the alignment and rigidity imparted by lumbar fusion influences the outcome of THA by increasing the risk of dislocation, due to the lack of spinal compensation during motion, which would be consistent with the findings of Riviere and colleagues.[13] Similarly, the 1.8 fold increased rate of implant aseptic loosening can be attributed to the stiff spine functionally adding a degree of constraint to the hip or a suboptimal functional acetabular orientation resulting in impingement and potentiating instability. edge loading and premature wear.[10] Furthermore, poor functional implant positioning, a lack of spinal motion to compensate for impact during a fall, an increased risk of falling and implant aseptic loosening may account for the 1.5 fold increased risk of periprosthetic fracture.[30] However, other factors such as the indication for the fusion and neurological dysfunction may confound these relationships by affecting the hip's peri-articular neuromuscular function and increasing the risk of falls in these patients.

With dislocation, aseptic loosening and fracture being increased in these patients it is not surprising that revision rates are 2.1 fold higher in patients with a prior lumbar fusion. However, it is harder to understand why PJI is increased unless the combination of a lumbar fusion and THA is an indication of a more comorbid, frail individual. Further research into this association is warranted.

Of interest, the relative complication rates remain significant even in patients with a short segment fusion. This is likely explained by most short segment lumbar fusions involving the lower lumbar spine between L4 and S1, which are known to provide the majority of lumbar lordosis and greatest effect on spinopelvic kinematics.[31] Although not directly compared, the forest plots would suggest that longer segment fusions carry higher dislocation, implant aseptic loosening and revision rates than short segment fusions, which would support a biomechanical cause for these complications (Supplementary Materials 4-5).

The results of this study permit a greater understanding of the implications of a prior fusion on the outcomes of a THA. The clinical relevance of which is to provides useful information to enable adequate counselling of the risks of THA and accounting for the patients spino-pelvic alignment when performing THA for these high-risk patients. However, it is unknown whether there is a need for surgical techniques to change. Contemporary techniques are available that attempt to determine the effects of an individual's spinopelvic motion on a THA during pre-operative planning with dynamic radiographs and 3D modelling. These adjuncts, and a move toward functional positioning of THA implants may reduce the complication profile in this subset of patients, but further evaluation of this claim is necessary. It may be appropriate in patients with a higher risk of dislocation due to previous spinal fusion or stiffness to use dual mobility implants due to their large effect size in reducing the risk of dislocation in observational studies.[32]

With ever increasing subspecialisation of hip arthroplasty surgeons and spinal surgeons, this research emphasises the importance of each discipline understanding the implications of pathology and interventions affecting other areas. A closer collaboration between these disciplines may improve patient outcomes as more knowledge is gained about the complex biomechanical interplay between the spine and hip.

The current study has some advantages compared to the previous review. Firstly, included several recent published reports, hence there was enhanced power to evaluate the associations. Secondly, we reported on a comprehensive list of outcomes previously not evaluated by An and colleagues in their review.[5] Lastly, we excluded two papers from the An et al. review, the first of which was the article by Perfetti and colleagues as this was considered a duplicate because the authors used the SPARCS database, which was also utilised in the

publication of Diebo and colleagues.[5,28,33] The second was the article by Eneqvist and colleagues which was excluded because it only reported patient reported outcomes.[34]

There are several important limitations which deserve consideration. First, there was significant heterogeneity between the contributing studies which could be attributed to study design characteristics; however, this could not be explored because of the limited number of studies available for pooling in each outcome. Second, majority of the risk estimates were estimated from raw counts, hence inability to account for confounding was an issue. Third, this study could not assess the time between fusion and THA, the spinopelvic parameters, the underlying condition necessitating lumbar fusion or THA, nor could it assess the method and implant choice of either fusion of THA. Fourth, the length of follow-up (range 90 days to 2.7 years) of included studies was short and may impact the true risk differences at intermediate and long-term follow-up. We were unable to conduct any sensitivity analyses given the limited number of studies and the fact that not all evaluated outcomes were reported by each of the included studies. Fifth, although we assessed the associations between outcomes and short or long segment fusion, we could not stratify the risk according to the number of levels fused because these data were not available. Sixth, the incidence and influence of lumbar spinal pathology, including stiffness and deformity, in the non-fused on the outcome of this study remains unclear. Seventh, some of the findings were based on single reports. Finally, because of lack of or inconsistent reporting, we were unable to assess patient reported outcomes or satisfaction scores.

Despite these limitations, this study has identified that patients with prior spinal fusion are at substantial risk of adverse events following primary THA, which suggests that measures to reduce the risk of these complications should be used in this high-risk population when undergoing primary THA. Additionally, these patient groups should also be counselled appropriately about their risks of undergoing THA.

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Tables

Table 1. Baseline characteristics of included articles (studies) (2016-2019)

Author, year of publication	Country	Year of study	Study design	Mean/median baseline age (years)	Males (%)	Follow-up period	No. of THRs	Quality score
Sing, 2016	USA	2005-2012	Retrospective cohort	<65-85+	38.0	2.0 years	598,995	8
Barry, 2017	USA	2012-2014	Retrospective cohort	68.4	42.9	90 days	105	7
Buckland, 2017	USA	2005-2012	Retrospective cohort	<65-85+*	38.5	1.0 year	853,677	8
Lazennec, 2017	France	2013-2015	Retrospective case-control	60.1-64.9	39.1	NR	243	4
Loh, 2017	Singapore	2006-2015	Prospective cohort	67.7	19.5	2.0 years	164	6
Diebo, 2018	USA	2009-2013	Retrospective cohort	63-65	44.0	NR	49,920	7
Gausden, 2018	USA	2012-2014	Retrospective cohort	64.5	45.1	6 months	207,285	6
King, 2018	USA	2005-2014	Retrospective cohort	>65	38.2	NR	880,405	5
York, 2018	USA	2010-2014	Retrospective cohort	61.3-63.5	37.1	2.7 years	509	4
Salib, 2019	USA	1998-2015	Retrospective cohort	71.0	44.0	6.0 years	291	6

*, baseline age range; NR, not reported

Figure Legends

Figure 1. PRISMA flow diagram

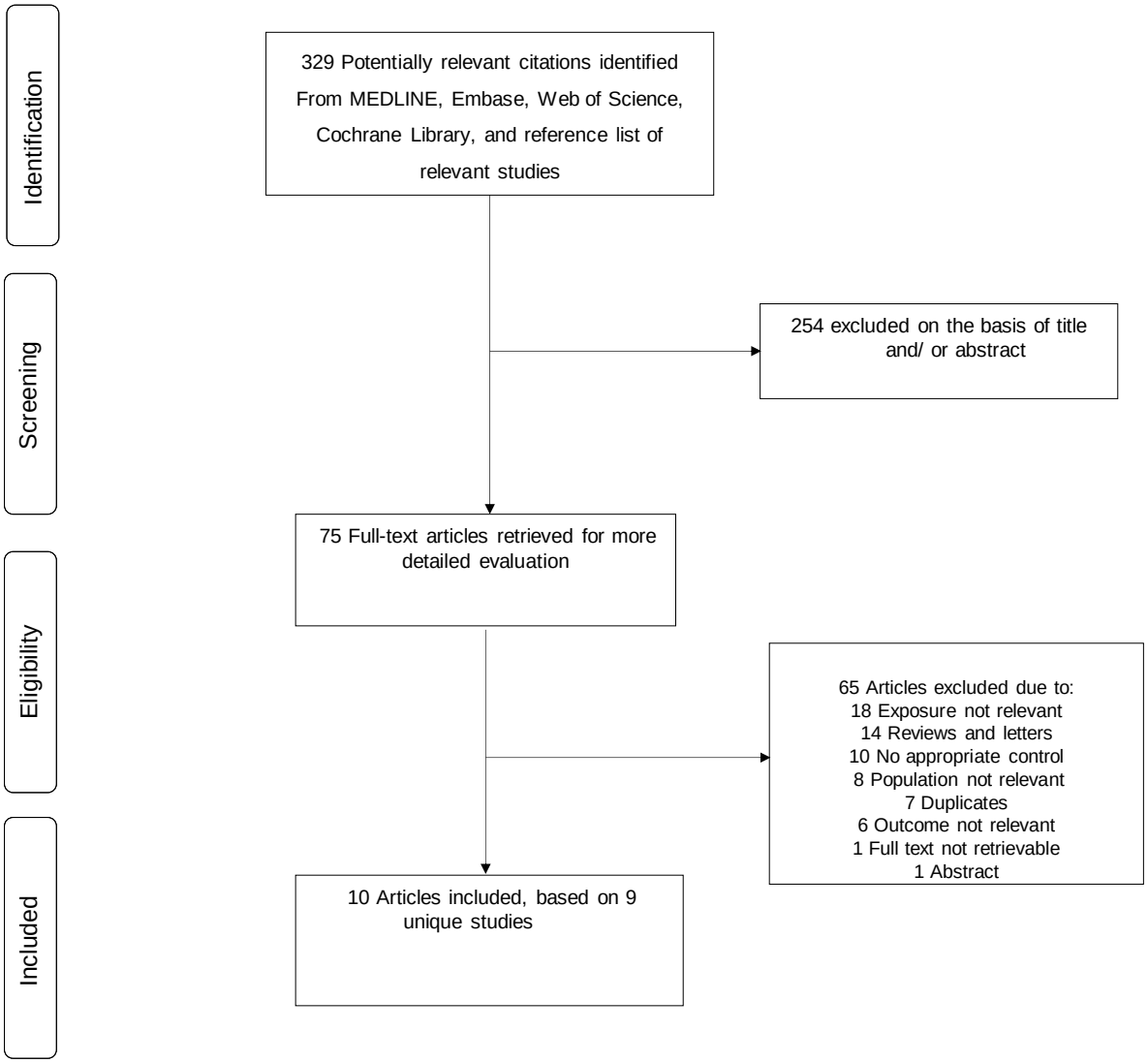


Figure 2. Risk of dislocation and revision comparing prior spinal fusion with no spinal fusion in THA (CI, confidence interval (bars); NR, not reported; RR, relative risk)

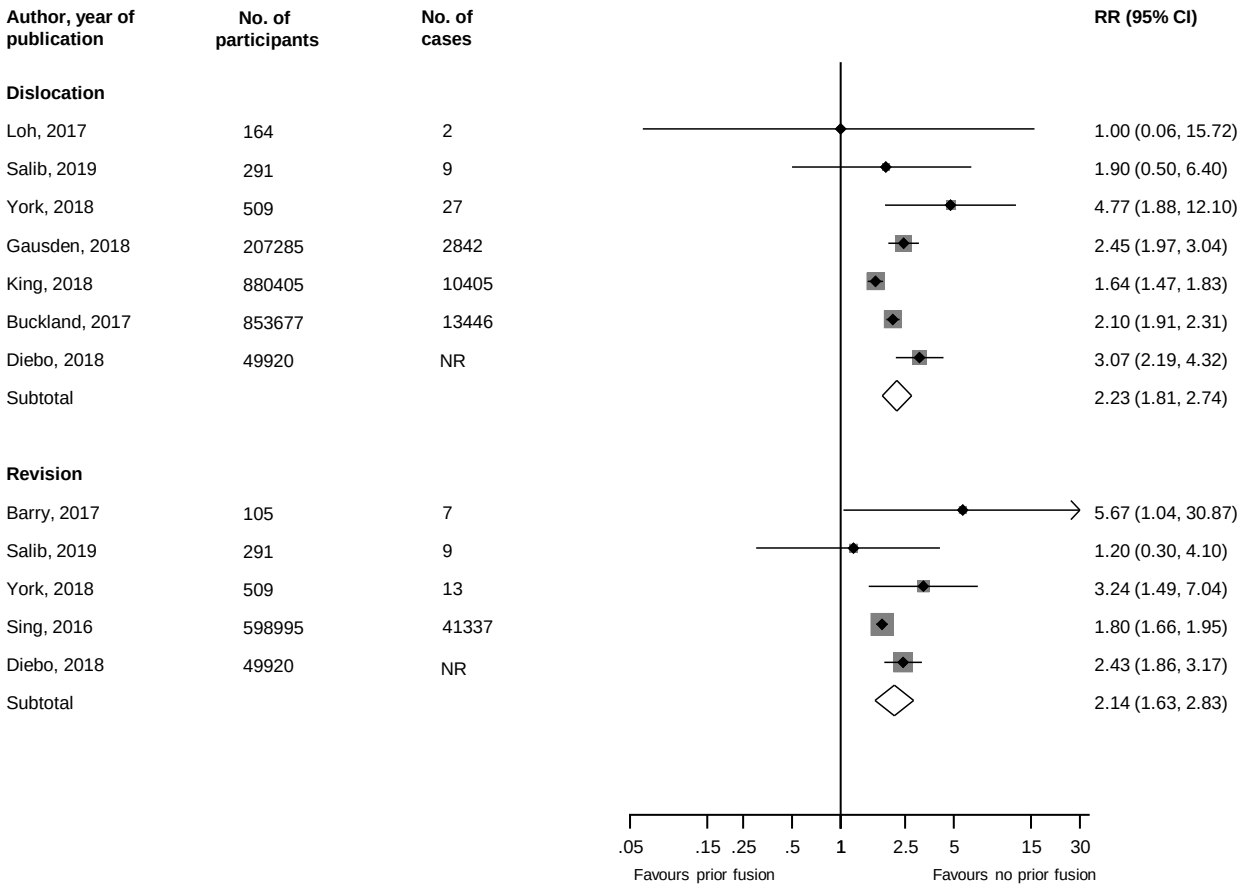
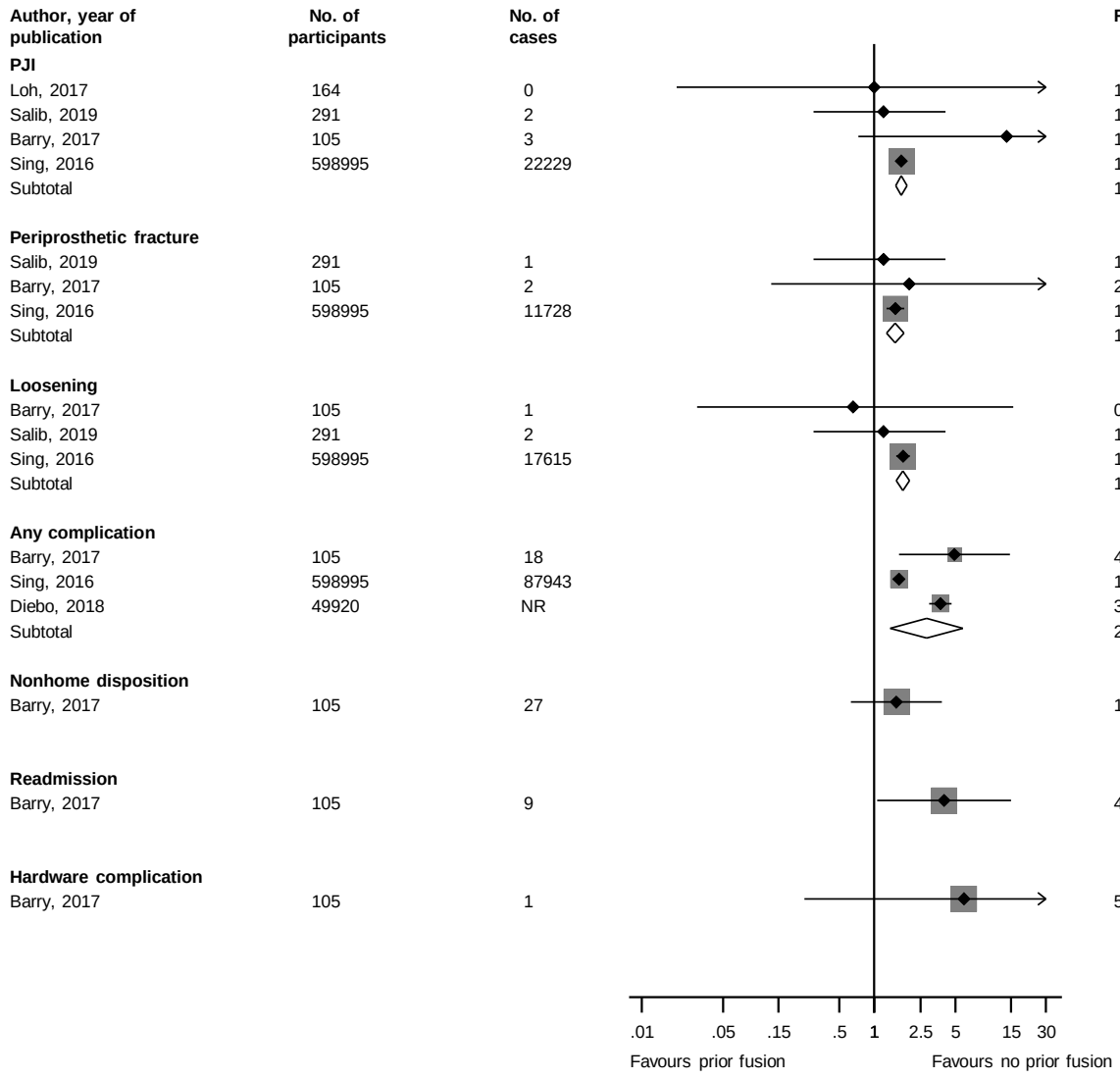


Figure 3. Risk of other complications comparing prior spinal fusion with no spinal fusion in THA **(**CI, confidence interval (bars); NR, not reported; PJI, prosthetic joint infection; RR, relative risk)



Supplementary Material

Supplementary Material 1	PRISMA checklist
Supplementary Material 2	MOOSE checklist
Supplementary Material 3	Literature search strategy
Supplementary Material 4	Risk of outcomes comparing prior short spinal fusion with no spinal fusion in primary THR
Supplementary Material 5	Risk of outcomes comparing prior long spinal fusion with no spinal fusion in primary THR

Supplementary Material 1. PRISMA checklist

Section/topic	Item No	Checklist item	Reported on page No
Title			
Title	1	Identify the report as a systematic review, meta-analysis, or both	1
Abstract			
Structured summary	2	Provide a structured summary including, as applicable, background, objectives, data sources, study eligibility criteria, participants, interventions, study appraisal and synthesis methods, results, limitations, conclusions and implications of key findings, systematic review registration number	2
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS)	5
Methods			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (such as web address), and, if available, provide registration information including registration number	2
Eligibility criteria	6	Specify study characteristics (such as PICOS, length of follow-up) and report characteristics (such as years considered, language, publication status) used as criteria for eligibility, giving rationale	6
Information sources	7	Describe all information sources (such as databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched	6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated	Supplementary Material 3
Study selection	9	State the process for selecting studies (that is, screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis)	6-7
Data collection process	10	Describe method of data extraction from reports (such as piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators	6-7
Data items	11	List and define all variables for which data were sought (such as PICOS, funding sources) and any assumptions and simplifications made	6-7
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis	7-8
Summary measures	13	State the principal summary measures (such as risk ratio, difference in means).	7-8
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (such as I^2 statistic) for each meta-analysis	7-8
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (such as publication bias, selective reporting within studies)	7-8
Additional analyses	16	Describe methods of additional analyses (such as sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified	7-8
Results			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram	8 and Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (such as study size, PICOS, follow-up period) and provide the citations	8-9, Table 1
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see item 12).	9-10, Table 1;
Results of individual studies	20	For all outcomes considered (benefits or harms), present for each study (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot	9-10, Figures 2-3
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency	9-10, Figures 2-3; Supplementary Materials 4-5
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see item 15)	
Additional analysis	23	Give results of additional analyses, if done (such as sensitivity or subgroup analyses, meta-regression) (see item 16)	N/A
Discussion			
Summary of evidence	24	Summarise the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (such as health care providers, users, and policy makers)	10
Limitations	25	Discuss limitations at study and outcome level (such as risk of bias), and at review level (such as incomplete retrieval of identified research, reporting bias)	13-14
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research	12-14
Funding			
Funding	27	Describe sources of funding for the systematic review and other support (such as supply of data) and role of funders for the systematic review	14

Supplementary Material 2. MOOSE checklist

Outcomes following primary total hip replacement with pre-existing spinal fusion surgery: A systematic review and meta-analysis of observational evidence

Criteria		Brief description of how the criteria were handled in the review
Reporting of background		
√	Problem definition	There is inconsistent evidence on whether prior spinal fusion surgery adversely impacts outcomes following total hip replacement (THR).
√	Hypothesis statement	Prior spinal fusion surgery is associated with worse outcomes following THR
√	Description of study outcomes	Dislocation, revision and reasons for revision
√	Type of exposure	Cemented, uncemented, hybrid, and reverse hybrid fixations
√	Type of study designs used	Comparative observational studies and randomised controlled trials
√	Study population	Primary THR
Reporting of search strategy should include		
√	Qualifications of searchers	Setor K. Kunutsor, PhD; MC Wyatt
√	Search strategy, including time period included in the synthesis and keywords	Time period: from inception to 28 Oct 2019 The detailed search strategy can be found in Supplementary Material 3
√	Databases and registries searched	MEDLINE, EMBASE, Web of Science, and Cochrane databases
√	Search software used, name and version, including special features	OvidSP was used to search EMBASE and MEDLINE EndNote used to manage references
√	Use of hand searching	We searched bibliographies of retrieved papers
√	List of citations located and those excluded, including justifications	Details of the literature search process are outlined in the flow chart. The citation list for excluded studies are available on request.
√	Method of addressing articles published in languages other than English	Not applicable
√	Method of handling abstracts and unpublished studies	Abstracts with no full text publications were not included.
√	Description of any contact with authors	None
Reporting of methods should include		
√	Description of relevance or appropriateness of studies assembled for assessing the hypothesis to be tested	Detailed inclusion and exclusion criteria are described in the Methods section.
√	Rationale for the selection and coding of data	Data extracted from each of the studies were relevant to the population characteristics, study design, exposure, and outcome.
√	Assessment of confounding	We assessed confounding by ranking individual studies on the basis of different adjustment levels
√	Assessment of study quality, including blinding of quality assessors; stratification or regression on possible predictors of study results	Study quality was assessed based on the nine-star Newcastle–Ottawa Scale using pre-defined criteria namely: population representativeness, comparability (adjustment of confounders), ascertainment of outcome. Sensitivity analyses by several quality indicators such as study size, duration of follow-up, and adjustment factors.
√	Assessment of heterogeneity	Heterogeneity of the studies was quantified with I^2 statistic that provides the relative amount of variance of the summary effect due to the between-study heterogeneity
√	Description of statistical methods in sufficient detail to be replicated	Description of methods of meta-analyses. We performed random effects meta-analysis with Stata 16.
√	Provision of appropriate tables and graphics	Table 1; Figures 1-3; Supplementary Materials 4-5
Reporting of results should include		
√	Graph summarizing individual study estimates and overall estimate	Figures 2-3; Supplementary Materials 4-5
√	Table giving descriptive information for each study included	Table 1
√	Results of sensitivity testing	Not applicable
√	Indication of statistical uncertainty of findings	95% confidence intervals were presented with all summary estimates, I^2 values and results of sensitivity analyses
Reporting of discussion should include		

√	Quantitative assessment of bias	Sensitivity analyses indicate heterogeneity in strengths of the association due to most common biases in observational studies. The systematic review is limited in scope, as it involves published data. Individual participant data is needed. Limitations have been discussed.
√	Justification for exclusion	All studies were excluded based on the pre-defined inclusion criteria in methods section.
√	Assessment of quality of included studies	Brief discussion included in 'Methods' section
Reporting of conclusions should include		
√	Consideration of alternative explanations for observed results	Discussion
√	Generalization of the conclusions	Discussed in the context of the results.
√	Guidelines for future research	Large-scale definitive studies needed
√	Disclosure of funding source	In "Acknowledgement" section

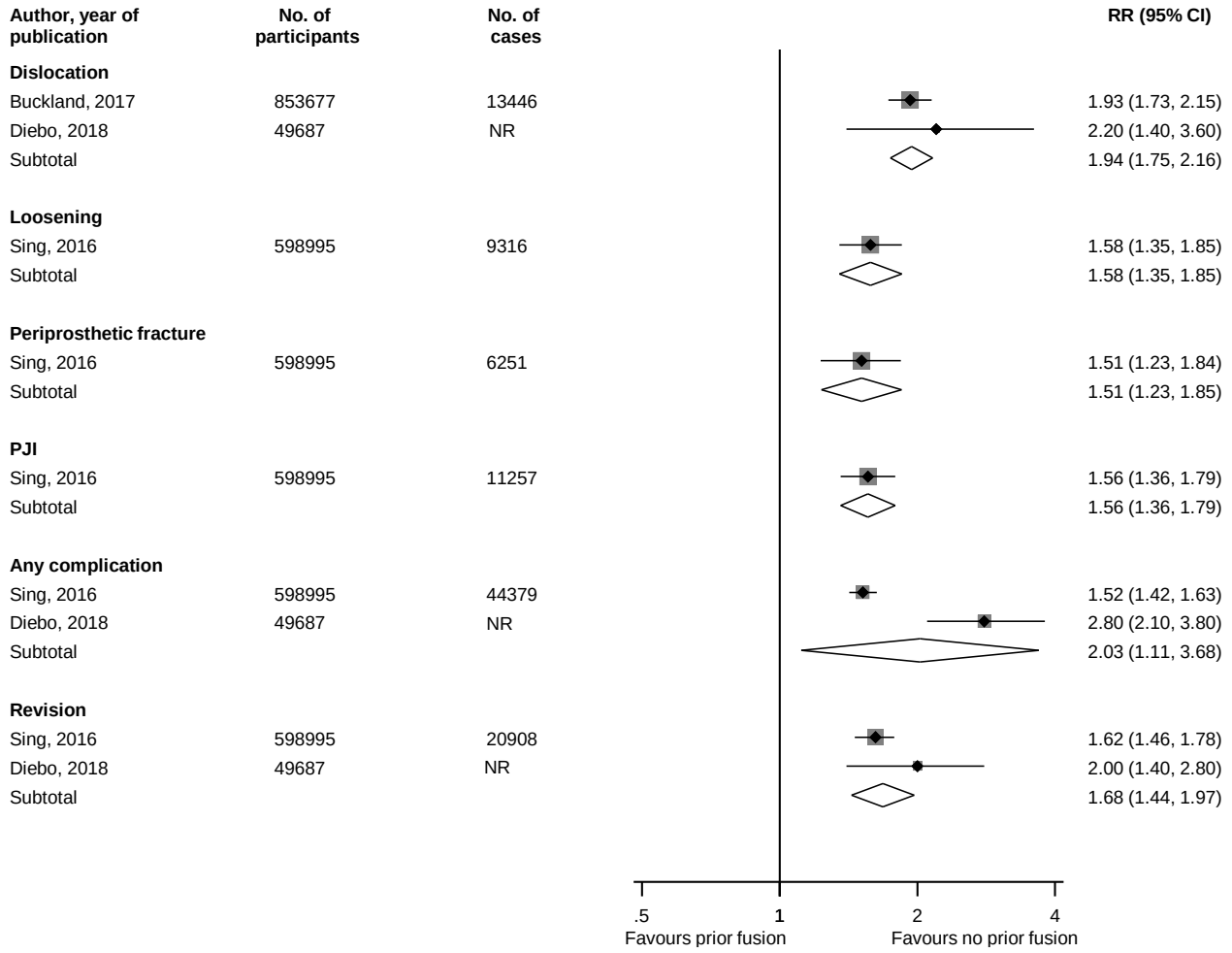
Supplementary Material 3. Literature search strategy

Relevant studies, published from inception to 28 October 2019 (date last searched), were identified through electronic searches using MEDLINE, EMBASE, and Cochrane databases. Electronic searches were supplemented by scanning reference lists of articles identified for all relevant studies (including review articles) and by hand searching of relevant journals.

Ovid MEDLINE 1946-Present
1 exp Spinal Fusion/ (22350)
2 spinal deformity.mp. (3269)
3 exp Spinal Curvatures/ (22206)
4 exp Spinal Stenosis/ (5438)
5 exp Arthroplasty, Replacement, Hip/ (23241)
6 hip arthroplasty.mp. (18637)
7 hip replacement.mp. (10187)
8 1 or 2 or 3 or 4 (44893)
9 5 or 6 or 7 (35143)
10 8 and 9 (121)
11 limit 10 to humans (117)

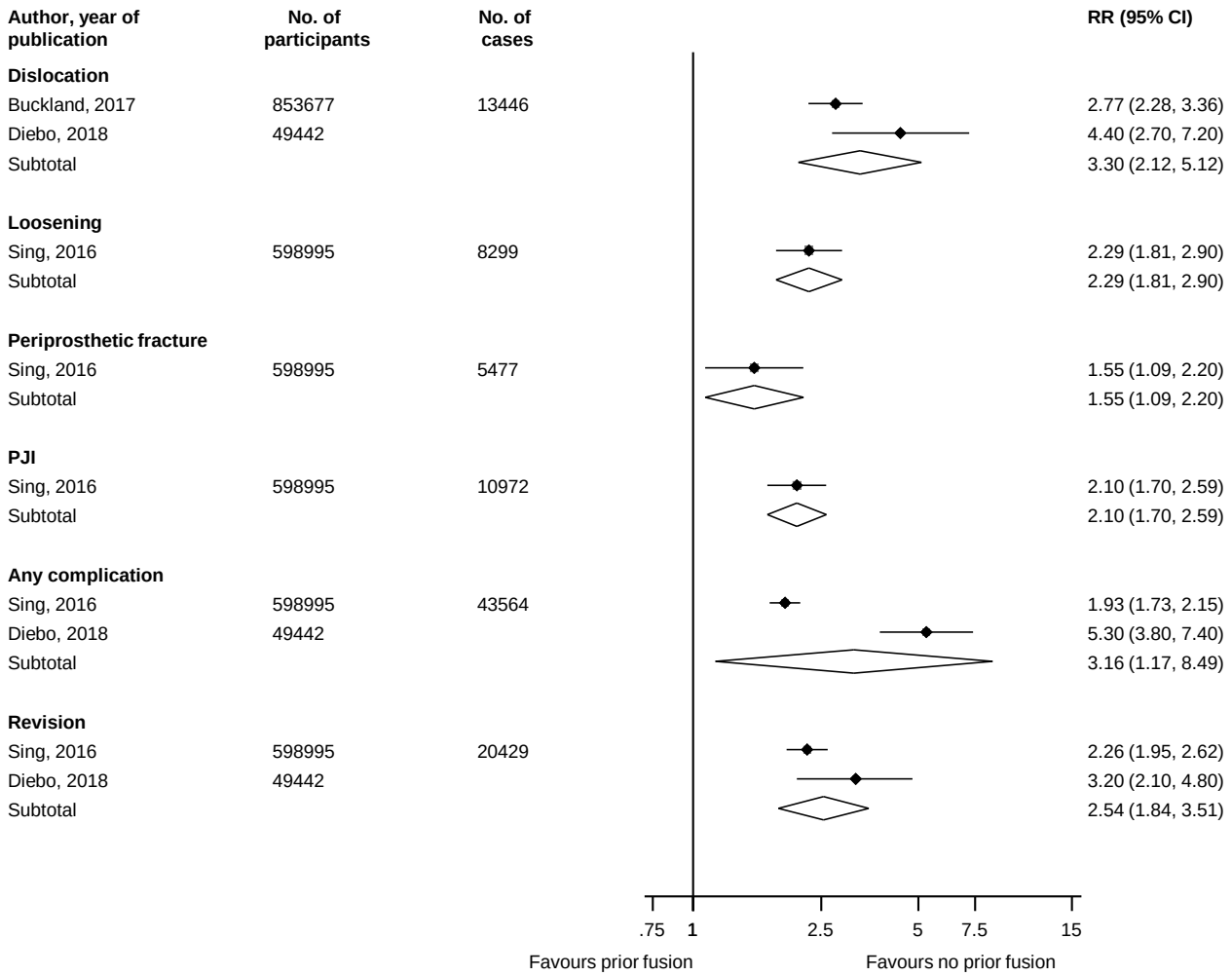
Each part was specifically translated for searching the other databases (EMBASE and Cochrane databases)

Supplementary Material 4. Risk of outcomes comparing prior short spinal fusion with no spinal fusion in primary THR



CI, confidence interval (bars); NR, not reported; PJI, prosthetic joint infection; RR, relative risk; THR, total hip replacement

Supplementary Material 5. Risk of outcomes comparing prior long spinal fusion with no spinal fusion in primary THR



CI, confidence interval (bars); PJI, prosthetic joint infection; RR, relative risk; THR, total hip replacement