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REVIEW ARTICLE

# Clinical outcomes and complication profile of total hip arthroplasty after lumbar spine fusion: a meta-analysis and systematic review

James Randolph Onggo[1] · Mithun Nambiar[1,2] · Jason Derry Onggo[1,3] · Kevin Phan[4] · Anuruban Ambikaipalan[1] · Sina Babazadeh[1,5] · Raphael Hau[1,6]

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## Abstract

**Background** Hip and spine pathology can alter the biomechanics of spino-pelvic mobility. Lumbar spine fusions can reduce the mobility of the lumbar spine and therefore result in compensatory femoral motion, contributing towards dislocations of THA.

**Purpose** This meta-analysis aims to determine the effect of pre-existing spine fusions on THA outcomes, and complication profile including hip dislocations, all-cause revisions and all complications.

**Methods** A multi-database search was performed according to PRISMA guidelines. All studies that compared patients who underwent THA with and without prior SF were included in the analysis.

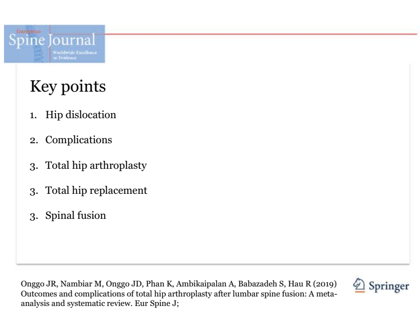
**Results** Ten studies were included in this review, consisting of 28,396 SF THA patients and 1,550,291 non-SF THA patients. There were statistically significant higher rates of hip dislocation (OR 2.20, 95% CI 1.71–2.85, $p<0.001$), all-cause revision (OR 3.43, 95% CI 1.96–6.00, $p<0.001$) and all complications (OR 2.83, 95% CI 1.28–6.24, $p=0.01$) in SF than in non-SF THA patients. When registry data were excluded, these rates were approximately doubled. Subgroup analysis of revisions for dislocations was not statistically significant (OR 5.28, 95% CI 0.76–36.87, $p=0.09$). While no meta-analysis was performed on clinical outcomes due to heterogeneous parameter reporting, individual studies reported significantly poorer outcomes in SF patients than in non-SF patients.

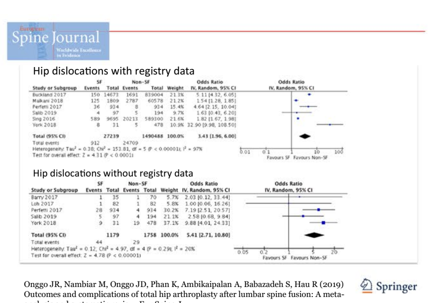
**Conclusion** THA patients with SF are at higher risks of hip dislocations, all-cause revisions and all complications, which may adversely affect patient-reported outcomes. Surgeons should be aware of these risks and appropriately plan to account for altered spino-pelvic biomechanics, in order to reduce the risks of hip dislocations and other complications.

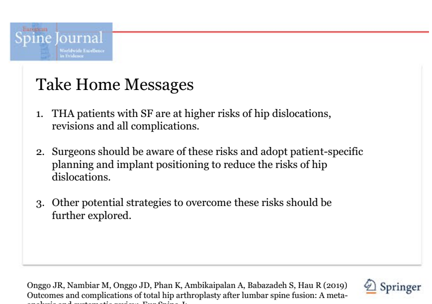
**Level of evidence** II (Meta-analysis of non-homogeneous studies).

### Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.




This work was primarily performed in Box Hill Hospital, Victoria, Australia.

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s00586-019-06201-z) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

**Keywords** Hip dislocation · Complications · Total hip arthroplasty · Total hip replacement · Spinal fusion

## Introduction

Total hip arthroplasty [10] is a highly successful procedure to treat degenerative joint disease. Successful THA is effective in improving quality of life (QoL), reducing pain and restoring function and independence [22, 40]. THA has been associated with excellent satisfaction and survivorship rates in recent years [21, 23, 54].

Hip dislocations in THA can occur as an early or late complication [58] with an incidence between 0.2 and 1.7% annually [53, 56, 58]. The aetiology of dislocations in THA is multifactorial, including patient-related, surgical technique-related or implant-related factors. Patient-related factors include age, previous femoral neck fractures and neuromuscular disorders [35, 36], while surgical technique- and implant-related factors include surgical approach, implant bearing surfaces, prosthesis design such as lipped liners and dual mobility constructs, soft tissue tensioning, as well as implant positioning and alignment [13]. Recurrent THA dislocations can significantly affect patient function and may require revision surgery.

Spino-pelvic mobility is normally coordinated to allow the balance of the mass of the trunk and hip motion when transitioning between standing and sitting [24]. When standing, the pelvis tilts anteriorly, resulting in reduced anteversion for an extended femur. On the other hand, sitting causes the pelvis to tilt posteriorly and allows for increased anteversion for a flexed femur [31]. However, when there is increased stiffness of the lumbar spine, such as with degenerative spine disease or spinal fusion, the loss of pelvic mobility leads to reduced pelvic tilting motion when changing positions between standing and sitting [24, 26, 52]. Reduced pelvic tilting causes biomechanical compensation of increased femoral movements for function and posture. As a result of this compensation, clinical consequences such as anterior or posterior impingement can lead to posterior or anterior dislocations of the femoral head, respectively [27].

This systematic review and meta-analysis aims to determine the effect of pre-existing spinal fusion [16] on THA functional outcomes, and complication profile including hip dislocations and revision surgery.

## Methods

### Literature search

This review was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) criteria [38]. A comprehensive search was conducted across multiple databases (PubMed, OVID MEDLINE, EMBASE) from the date of database inception until 18th February 2019. The Medical Subject Heading and Boolean operator terms utilised for the search were: [('Total hip arthroplasty' OR 'Total hip replacement') AND ('Spinal fusion' OR 'lumbar fusion')]. Identified articles and their corresponding references were reviewed according to the selection criteria for consideration of inclusion.

### Selection criteria

All articles of any study design directly comparing the functional outcomes and rates of hip dislocation in primary THA patients with and without prior spinal fusion were considered for inclusion. Non-English-language studies, non-peer-reviewed studies, unpublished manuscripts and studies not directly comparing hip dislocation rates in THA patients with and without prior spinal fusion were excluded. Two independent authors reviewed records retrieved from the initial search and excluded irrelevant ones. Titles and abstracts of the remaining articles were then screened against the inclusion criteria. Included articles were critically reviewed according to a predefined data extraction form.

### Data extraction

Extracted data parameters included details on study designs, publication years, patient numbers, basic demographics, clinical functional outcomes, anteversion and inclination angles, and rates of hip dislocations, complications and revisions. Functional outcomes included the EuroQoL 5-Dimension (EQ-5D), Hospital for Special Surgery (HSS) score, Oxford Hip Score (OHS), 36-Item Short Form Health Survey (SF-36), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores and visual analogue scale (VAS) in pain and satisfaction. Complications included all operative and non-operative complications related to the index THA procedure. Operative complications include peri-prosthetic infections, hip dislocations, peri-prosthetic fractures, loosening and instability amongst others, while non-operative complications include cardiopulmonary events, venous thromboembolic events and sepsis amongst others. Revision was considered when there was an exchange of one of the THA components, including liners, for any cause.

### Methodology assessment

Quality of the methodology of the included studies was assessed with the Methodological Index for

Non-Randomized Studies (MINORS) [50]. MINORS used 12 criteria to assess non-randomised comparative studies. Each criterion is scored with a 3-point system from 0 to 2 (0: not reported, 1: inadequately reported and 2: adequately reported). The ideal score is 24 points.

### Statistical analysis

Odds ratio (OR) was used as a summary statistic. In the present study, both fixed- and random-effects models were tested. In the fixed-effects model, it was assumed that the treatment effect in each study was the same, whereas in a random-effects model, it was assumed that there were variations between studies. Heterogeneity between trials was tested using $x^2$ tests. $I^2$ statistic was used to estimate the percentage of total variation across studies, owing to heterogeneity rather than chance, with values greater than 50% considered as substantial heterogeneity. $I^2$ can be calculated as: $I^2 = 100\% \times (Q - df)/Q$, with Q defined as Cochrane's heterogeneity statistics and *df* defined as degree of freedom. If there was substantial heterogeneity, the possible clinical and methodological reasons for this were explored qualitatively. In the present meta-analysis, the results using the random-effects model were presented to take into account the possible clinical diversity and methodological variation between studies. Specific analyses considering confounding factors were not possible because raw data were not available. All *p* values were two-sided. Review Manager (version 5.3, Copenhagen, The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) was used for statistical analysis.

## Results

### Literature search

A selection process flowchart to identify the included studies according to PRISMA guidelines is illustrated in Fig. 1. A total of 329 studies were identified from the initial search, of which 109 duplicates and 23 non-English-language articles were excluded. Titles and abstracts of the remaining 197 studies were screened in accordance with the predefined inclusion criteria. A total of 10 studies were included, consisting of one retrospective [57], five case–control [5, 15, 30, 42, 48] and four registry data [6, 9, 32, 49] studies. Study details are presented in Table 1.

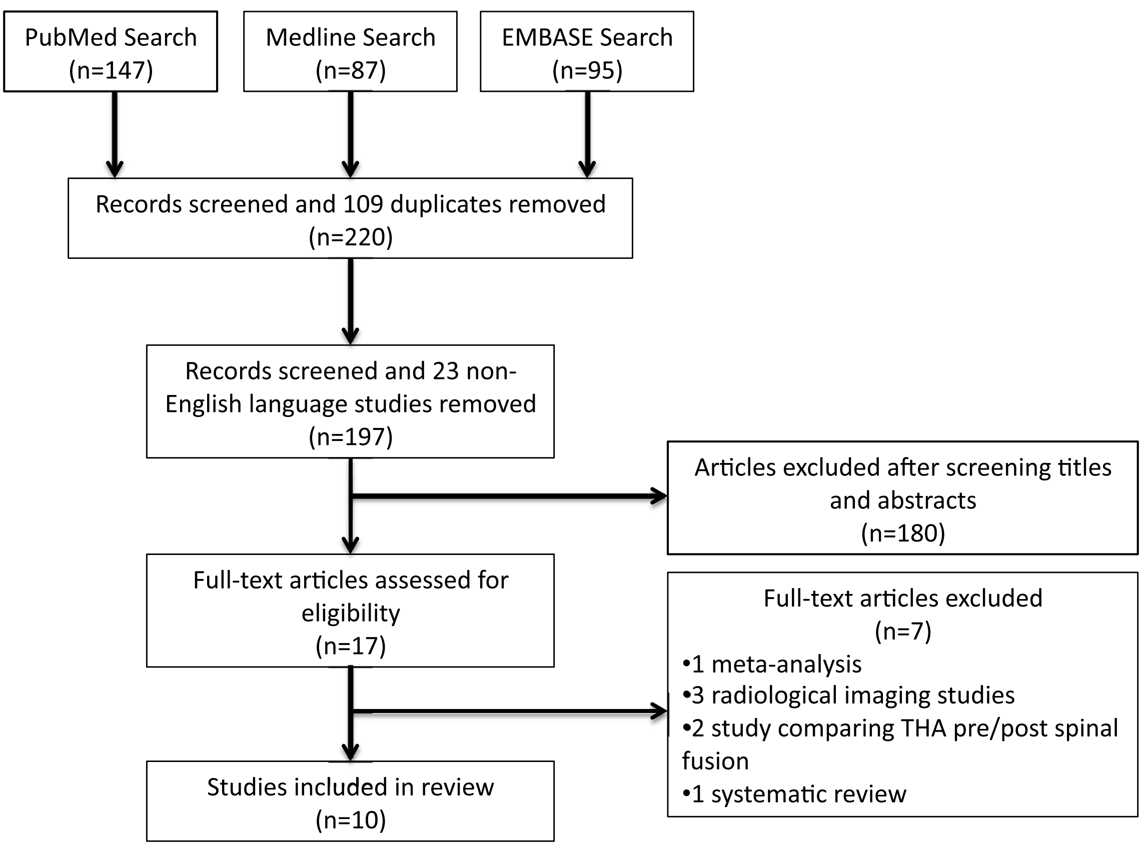



**Fig. 1** PRISMA search flowchart

**Table 1** Study details and patient demographics

| Article | Study design | Level of evidence | No. of hips | | | Gender | | | | Mean age | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SF | Non-SF | Total | SF | | Non-SF | | SF | Non-SF |
| | | | | | | Male | Female | Male | Female | | |
| Barry 2017 | Case–control | LOE III | 35 | 70 | 105 | 21 | 14 | 39 | 31 | 68.5 | 68.4 |
| Bedard 2016 | Registry | LOE IV | 48 | 58,654 | 58,702 | – | – | – | – | – | – |
| Buckland 2017 | Registry | LOE IV | 14,668 | 839,004 | 853,672 | 5030 | 9638 | 323,673 | 515,331 | – | – |
| Eneqvist 2017 | Case–control | LOE III | 997 | 997 | 1994 | 408 | 589 | 402 | 595 | 70.3 | 70.2 |
| Loh 2017 | Case–control | LOE III | 82 | 82 | 164 | 16 | 68 | 16 | 68 | 67.59 | 67.68 |
| Malkani 2018 | Registry | LOE IV | 1809 | 60,578 | 62,387 | – | – | – | – | – | – |
| Perfetti 2017 | Case–control | LOE III | 934 | 934 | 1868 | 343 | 591 | 372 | 562 | 64.5 | 64.5 |
| Salib 2019 | Case–control | LOE III | 97 | 194 | 291 | 43 | 54 | 86 | 108 | 71 | 71 |
| Sing 2016 | Registry | LOE IV | 9695 | 589,300 | 598,995 | 3282 | 6412 | 224,523 | 364,777 | – | – |
| York 2018 | Retrospective | LOE III | 31 | 478 | 509 | 7 | 24 | 182 | 296 | 63.5 | 61.3 |

| Article | Mean BMI | | Mean time from fusion to THA/years | THA approach | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SF | Non-SF | | SF | | | Non-SF | | |
| | | | | Anterior | Lateral | Posterior | Anterior | Lateral | Posterior |
| Barry 2017 | – | – | – | 1 | 18 | 16 | 6 | 43 | 21 |
| Bedard 2016 | – | – | – | – | – | – | – | – | – |
| Buckland 2017 | – | – | – | – | – | – | – | – | – |
| Eneqvist 2017 | – | – | – | – | – | 510 | – | – | 554 |
| Loh 2017 | 26.5 | 26.5 | 3.6 | – | – | – | – | – | – |
| Malkani 2018 | – | – | – | – | – | – | – | – | – |
| Perfetti 2017 | – | – | – | – | – | – | – | – | – |
| Salib 2019 | 30 | 30 | – | 9 | 49 | 39 | 18 | 98 | 78 |
| Sing 2016 | – | – | – | – | – | – | – | – | – |
| York 2018 | – | – | – | – | – | – | – | – | – |

*SF* spinal fusion

The MINORS scores for non-randomised studies are detailed in Table 2.

## Methodology assessment

MINORS scores for all ten studies averaged at 16.8 with a minimum of 14 and a maximum of 22. MINORS scores for each criterion are presented in Table 3.

## Demographics

There were 28,396 SF patients and 1,578,687 non-SF patients included in the study. The majority of patients in both groups were female, making up 61.2% and 55.9% of SF and non-SF patients, respectively. Due to the nature of the included studies, there was a lack of reporting of individual raw data. Information regarding the type of spinal fusion, indications for THA and bearing surfaces was not consistently available. Furthermore, other important factors that may potentially influence hip dislocation rates, such as timing of spinal fusion before THA, were only reported by Loh [30] to be at a mean of 3.6 years. A quantitative analysis comparing the mean age of the patients included at the time of THA showed no statistically significant difference between both groups (Fig. 2). This suggests a weak propensity for age to be a significant confounding factor for the differences in outcomes between both groups. Other important confounding factors such as weight and propensity for degenerative articular changes were not considered in individual studies. No further analysis could be performed.

## Complications

Meta-analysis was performed on rates of hip dislocations, revisions and complications, both including and excluding registry studies, as shown in Figs. 3, 4, 5 and Figs. 6, 7, 8 respectively. Subgroup analysis of revision rates is shown in Fig. 9.

**Table 2** MINORS bias assessment of included non-randomised studies

| Articles | Clearly stated aim | Inclusion of consecutive patients | Prospective collection of data | Endpoints appropriate study aims | Unbiased assessment of endpoints | Follow-up period appropriate | Loss to follow-up less than 5% | Prospective calculation of study size | Adequate control group | Contemporary groups | Baseline equivalence of groups | Adequate statistical analyses | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barry 2017 | 2 | 0 | 0 | 2 | 1 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 15 |
| Bedard 2016 | 2 | 1 | 0 | 2 | 1 | 2 | 0 | 0 | 1 | 2 | 1 | 2 | 14 |
| Buckland 2017 | 1 | 2 | 0 | 2 | 1 | 2 | 0 | 0 | 2 | 2 | 1 | 2 | 15 |
| Eneqvist 2017 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 22 |
| Loh 2017 | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 20 |
| Malkani 2018 | 2 | 2 | 0 | 2 | 1 | 2 | 0 | 0 | 2 | 2 | 1 | 2 | 14 |
| Perfetti 2017 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 0 | 1 | 2 | 1 | 2 | 16 |
| Salib 2019 | 2 | 1 | 0 | 2 | 1 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 18 |
| Sing 2016 | 2 | 1 | 0 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 1 | 2 | 16 |
| York 2018 | 2 | 2 | 0 | 2 | 2 | 2 | 1 | 0 | 2 | 2 | 1 | 2 | 18 |

Each item is scored with either 0 (not reported), 1 (inadequately reported) or 2 (adequately reported)

**Table 3** Patient-related outcome measures and anteversion inclination angles

| Article | Outcome measure | SF | No SF | *p* value |
|---|---|---|---|---|
| Eneqvist 2017 | EQ-5D Index | 0.66 | 0.75 | 0.05 |
| | EQ-VAS | 66.3 | 73.1 | 0.08 |
| | Pain VAS | 20.4 | 16.1 | 0.04 |
| | Satisfaction VAS | 16.7 | 22.7 | < 0.001 |
| Loh 2017 | Oxford | 86.08 | 78.25 | < 0.001 |
| | SF-36 | 69.21 | 79.71 | < 0.001 |
| | WOMAC | 213.5 | 267.41 | < 0.001 |
| | HHS | 81 | 84 | 0.03 |
| Salib 2019 | Anteversion | 20 | 18 | 0.02 |
| | Inclination | 45 | 43 | 0.009 |
| York 2018 | Anteversion | 26.8 | 21.4 | 0.0093 |
| | Inclination | 39.9 | 39.6 | 0.841 |

*SF* spinal fusion

The rates of hip dislocation (OR 2.20, 95% CI 1.71–2.85, $p < 0.001$), all-cause revisions (OR 3.43, 95% CI 1.96–6.00, $p < 0.001$) and all complications (OR 2.83, 95% CI 1.28–6.24, $p = 0.01$) were consistently higher in the SF than in the non-SF THA patient group. When registry data were excluded, the rates of hip dislocation (OR 5.41, 95% CI 2.71–10.80, $p < 0.001$), all-cause revisions (OR 6.34, 95% CI 1.37–29.30, $p = 0.02$) and all complications (OR 4.62, 95% CI 2.20–9.69, $p < 0.001$) were approximately doubled in the SF than in the non-SF THA patient groups. A subgroup analysis of revision rates solely indicated for recurrent hip dislocations was also performed and showed no statistically significant difference between both groups (OR 5.28, 95% CI 0.76–36.87, $p = 0.09$).

## Clinical outcomes

Meta-analysis could not be performed for patient-reported outcome measures (PROM) due to the heterogeneity of outcome measures utilised in individual studies. In general, THA patients in the non-SF group had significantly better clinical outcome measures than those in the SF group. A summary of outcome measure data is presented in Table 3.

## Radiographic outcomes

Two studies [48, 57] reported the baseline characteristics of anteversion and inclination of acetabular components in SF and non-SF patients. A statistically significant greater anteversion was noted in the SF than in the non-SF group by Salib [48] (20° vs 18°, $p = 0.02$) and York [57] (26.8° vs 21.4°, $p = 0.009$). However, Salib [48] reported a statistically significant difference in inclination (45° vs 43°, $p = 0.009$), but York [57] did not (39.9° vs 39.6°, $p = 0.841$). No studies

| Study or Subgroup | SF Mean | SF SD | SF Total | Non-SF Mean | Non-SF SD | Non-SF Total | Weight | Mean Difference IV, Fixed, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Barry 2017 | 68.5 | 9.2 | 35 | 68.4 | 10.6 | 70 | 3.5% | 0.10 [−3.83, 4.03] |
| Eneqvist 2017 | 70.3 | 8.9 | 997 | 70.2 | 10.2 | 997 | 76.9% | 0.10 [−0.74, 0.94] |
| Loh 2017 | 67.59 | 8.32 | 82 | 67.68 | 8.35 | 82 | 8.3% | −0.09 [−2.64, 2.46] |
| Salib 2019 | 71 | 9 | 97 | 71 | 9 | 194 | 11.3% | 0.00 [−2.19, 2.19] |
| **Total (95% CI)** | | | **1211** | | | **1343** | **100.0%** | **0.07 [−0.66, 0.81]** |

Heterogeneity: $Chi^2 = 0.02$, df = 3 (P = 1.00); $I^2 = 0\%$
Test for overall effect: Z = 0.19 (P = 0.85)

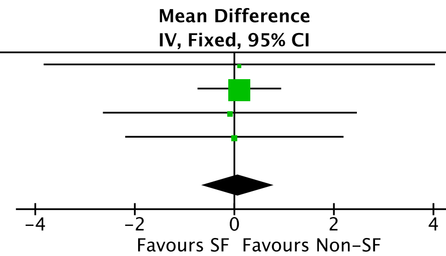



**Fig. 2** Mean age difference

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Barry 2017 | 1 | 35 | 1 | 70 | 0.8% | 2.03 [0.12, 33.44] |
| Bedard 2016 | 4 | 48 | 1700 | 58654 | 5.1% | 3.05 [1.09, 8.49] |
| Buckland 2017 | 364 | 14668 | 12982 | 839004 | 26.9% | 1.62 [1.46, 1.80] |
| Loh 2017 | 1 | 82 | 1 | 82 | 0.8% | 1.00 [0.06, 16.26] |
| Malkani 2018 | 134 | 1809 | 2908 | 60578 | 24.8% | 1.59 [1.33, 1.90] |
| Perfetti 2017 | 28 | 934 | 4 | 934 | 4.9% | 7.19 [2.51, 20.57] |
| Salib 2019 | 5 | 97 | 4 | 194 | 3.2% | 2.58 [0.68, 9.84] |
| Sing 2016 | 488 | 9695 | 13907 | 589300 | 27.2% | 2.19 [2.00, 2.41] |
| York 2018 | 9 | 31 | 19 | 478 | 6.3% | 9.88 [4.01, 24.33] |
| **Total (95% CI)** | | **27399** | | **1549294** | **100.0%** | **2.20 [1.71, 2.85]** |
| Total events | 1034 | | 31526 | | | |

Heterogeneity: $Tau^2 = 0.06$; $Chi^2 = 42.14$, df = 8 (P < 0.00001); $I^2 = 81\%$
Test for overall effect: Z = 6.06 (P < 0.00001)

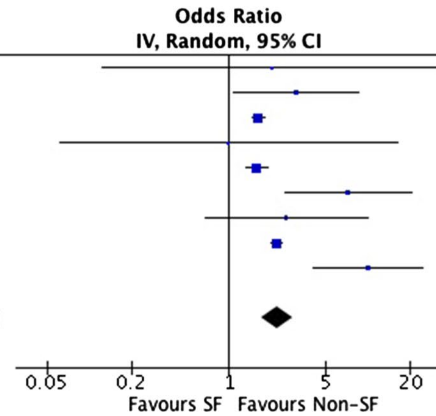



**Fig. 3** Hip dislocations with registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Buckland 2017 | 150 | 14673 | 1691 | 839004 | 21.3% | 5.11 [4.32, 6.05] |
| Malkani 2018 | 125 | 1809 | 2787 | 60578 | 21.2% | 1.54 [1.28, 1.85] |
| Perfetti 2017 | 36 | 934 | 8 | 934 | 15.4% | 4.64 [2.15, 10.04] |
| Salib 2019 | 4 | 97 | 5 | 194 | 9.7% | 1.63 [0.43, 6.20] |
| Sing 2016 | 589 | 9695 | 20213 | 589300 | 21.6% | 1.82 [1.67, 1.98] |
| York 2018 | 8 | 31 | 5 | 478 | 10.9% | 32.90 [9.98, 108.50] |
| **Total (95% CI)** | | **27239** | | **1490488** | **100.0%** | **3.43 [1.96, 6.00]** |
| Total events | 912 | | 24709 | | | |

Heterogeneity: $Tau^2 = 0.38$; $Chi^2 = 153.81$, df = 5 (P < 0.00001); $I^2 = 97\%$
Test for overall effect: Z = 4.31 (P < 0.0001)

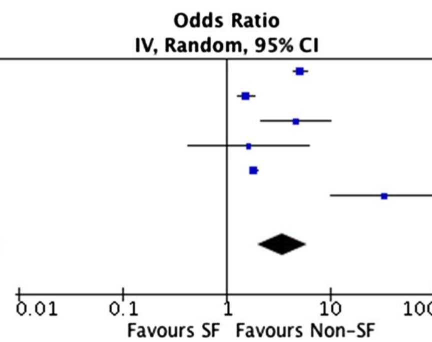



**Fig. 4** Revisions with registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Barry 2017 | 12 | 35 | 6 | 70 | 24.2% | 5.57 [1.87, 16.55] |
| Loh 2017 | 1 | 82 | 1 | 82 | 6.8% | 1.00 [0.06, 16.26] |
| Salib 2019 | 11 | 97 | 5 | 194 | 24.3% | 4.83 [1.63, 14.34] |
| Sing 2016 | 1155 | 9695 | 43019 | 589300 | 44.7% | 1.72 [1.61, 1.83] |
| **Total (95% CI)** | | **9909** | | **589646** | **100.0%** | **2.83 [1.28, 6.24]** |
| Total events | 1179 | | 43031 | | | |

Heterogeneity: $Tau^2 = 0.36$; $Chi^2 = 8.05$, df = 3 (P = 0.05); $I^2 = 63\%$
Test for overall effect: Z = 2.58 (P = 0.010)

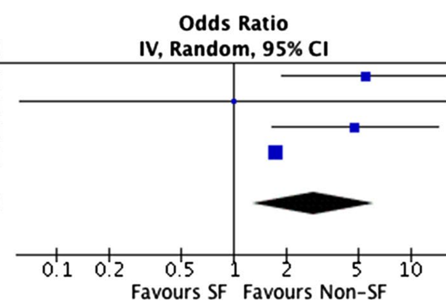



**Fig. 5** All complications with registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Barry 2017 | 1 | 35 | 1 | 70 | 5.7% | 2.03 [0.12, 33.44] |
| Loh 2017 | 1 | 82 | 1 | 82 | 5.8% | 1.00 [0.06, 16.26] |
| Perfetti 2017 | 28 | 934 | 4 | 934 | 30.2% | 7.19 [2.51, 20.57] |
| Salib 2019 | 5 | 97 | 4 | 194 | 21.1% | 2.58 [0.68, 9.84] |
| York 2018 | 9 | 31 | 19 | 478 | 37.1% | 9.88 [4.01, 24.33] |
| **Total (95% CI)** | | **1179** | | **1758** | **100.0%** | **5.41 [2.71, 10.80]** |
| Total events | 44 | | 29 | | | |

Heterogeneity: $Tau^2 = 0.12$; $Chi^2 = 4.97$, df = 4 (P = 0.29); $I^2 = 20\%$
Test for overall effect: Z = 4.78 (P < 0.00001)

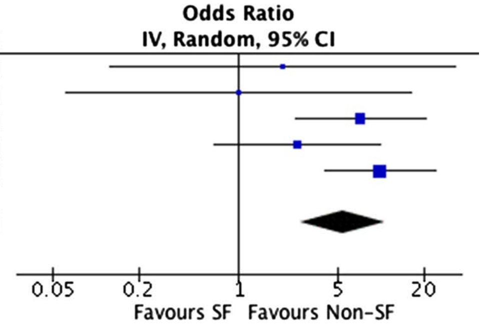



**Fig. 6** Hip dislocations without registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Perfetti 2017 | 36 | 934 | 8 | 934 | 36.7% | 4.64 [2.15, 10.04] |
| Salib 2019 | 4 | 97 | 5 | 194 | 30.9% | 1.63 [0.43, 6.20] |
| York 2018 | 8 | 31 | 5 | 478 | 32.5% | 32.90 [9.98, 108.50] |
| **Total (95% CI)** | | **1062** | | **1606** | **100.0%** | **6.34 [1.37, 29.30]** |
| Total events | 48 | | 18 | | | |

Heterogeneity: $Tau^2 = 1.51$; $Chi^2 = 11.90$, df = 2 (P = 0.003); $I^2 = 83\%$
Test for overall effect: Z = 2.36 (P = 0.02)

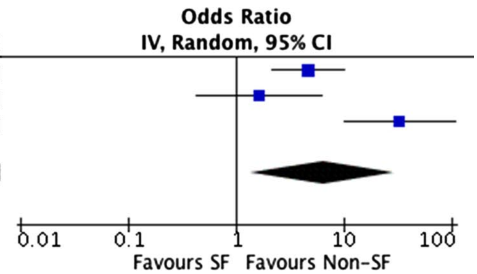



**Fig. 7** Revisions without registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Barry 2017 | 12 | 35 | 6 | 70 | 46.4% | 5.57 [1.87, 16.55] |
| Loh 2017 | 1 | 82 | 1 | 82 | 7.1% | 1.00 [0.06, 16.26] |
| Salib 2019 | 11 | 97 | 5 | 194 | 46.6% | 4.83 [1.63, 14.34] |
| **Total (95% CI)** | | **214** | | **346** | **100.0%** | **4.62 [2.20, 9.69]** |
| Total events | 24 | | 12 | | | |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.28$, df = 2 (P = 0.53); $I^2 = 0\%$
Test for overall effect: Z = 4.04 (P < 0.0001)

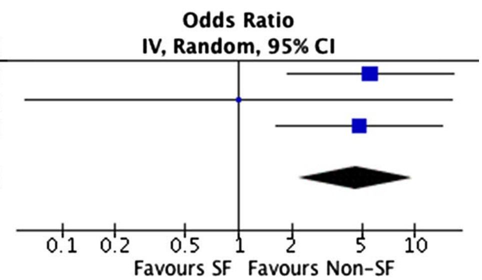



**Fig. 8** All complications without registry data

| Study or Subgroup | SF Events | SF Total | Non-SF Events | Non-SF Total | Weight | Odds Ratio IV, Random, 95% CI |
|---|---|---|---|---|---|---|
| Perfetti 2017 | 36 | 934 | 8 | 934 | 40.9% | 4.64 [2.15, 10.04] |
| Salib 2019 | 0 | 97 | 3 | 194 | 21.6% | 0.28 [0.01, 5.49] |
| York 2018 | 8 | 31 | 5 | 478 | 37.5% | 32.90 [9.98, 108.50] |
| **Total (95% CI)** | | **1062** | | **1606** | **100.0%** | **5.28 [0.76, 36.87]** |
| Total events | 44 | | 16 | | | |

Heterogeneity: $Tau^2 = 2.25$; $Chi^2 = 12.05$, df = 2 (P = 0.002); $I^2 = 83\%$
Test for overall effect: Z = 1.68 (P = 0.09)

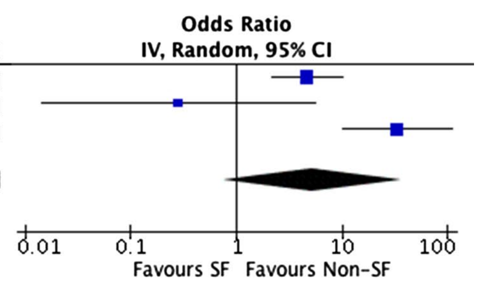



**Fig. 9** Revisions indicated for hip dislocations only

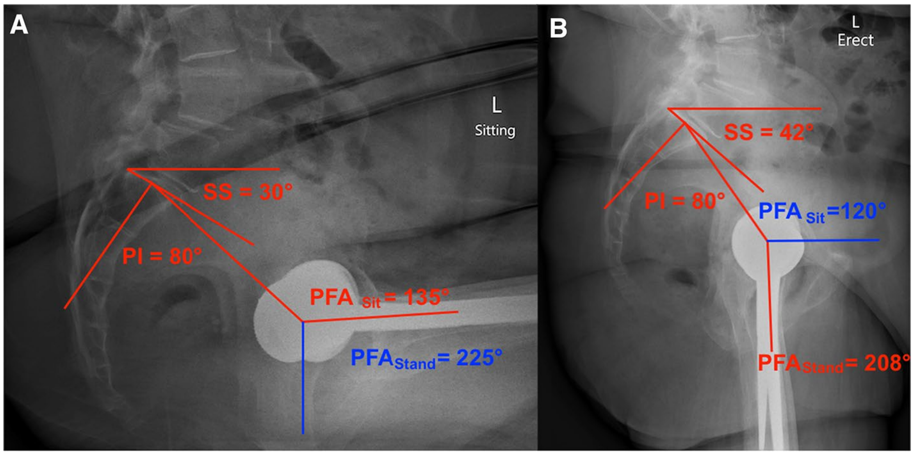



**Fig. 10** Lateral X-rays of a patient in sitting and standing positions depicting the biomechanical changes in pelvicfemoral angle (PFA) and sacral slope (SS) from a sitting (Image A) to standing (Image B) position. With a mobile spino-pelvic complex, from sitting to standing the SS increases from 30° to 42°, which represents an increased anterior pelvic tilt. The actual PFA is represented in red text, while the apparent PFA is in blue text. From Image A, a stuck-sitting phenomenon occurs when the SS remains at a low value (30°), even when changing from a sitting (red) to standing (blue) position. As such, compensatory femoral motion may result in a larger PFA (225° compared with a physiogical PFA of 208°) when standing to accommodate this pelvic stiffness. This increases the risks of posterior impingement and anterior dislocation. On the other hand, from Image B, a stuck-standing phenomenon occurs when the ST remains at a high value (42°), even when moving from a standing (red) to a sitting (blue) position. As such, compensatory femoral motion may result in a smaller PFA (120° compared with a physiogical PFA of 135°) when sitting to accommodate this pelvic stiffness. Hence, this increases the risks of anterior impingement and posterior dislocation

performed comparisons of lumbar lordosis, pelvic incidence or pelvic tilt between the SF and non-SF groups.

## Discussion

The rates of hip dislocations, revisions and all complications were 2.2, 3.6 and 2.8 times higher in the SF than in the non-SF THA patients, respectively. When registry data were excluded, the rates of hip dislocations, revisions and all complications in THA patients with SF approximately doubled to 5.4, 6.3 and 4.6 times higher than in those without SF, respectively. This may be explained by the presence of type 2 errors, caused by insufficient detection of complications with multicentre data, as well as underreporting of complications by institution-based joint replacement registries included in the study. This underreporting can be attributed to the dynamic geographical movements of patients, thus presenting with complications to institutions outside of the registry instead. Furthermore, for a proportion of hip dislocations, there is no need to undergo revision surgery or a closed reduction in the operating room.

A previous meta-analysis by An [2], which analysed six articles, also reported similar results but was of lower magnitude. There are four large-scale studies that were published after the previous meta-analysis and have been included in this analysis. Furthermore, An [2] did not investigate the rates of hip dislocations and revisions without registry data. The omission of registry data allows for a more comparable weightage contribution of each study to the final result. Furthermore, there may be underreporting of complications in registry data due to a less thorough detection of complications and loss to follow-up of patients. This puts registry data at a lower evidence level than the cohort and case–control studies. Hence, the subgroup analysis would be a more representative value of the associations being investigated.

The rate of revision associated with recurrent hip dislocations only was also analysed and, though not statistically significant, was trending towards significance ($p = 0.09$). We note that this may be due to a lack of papers specifically examining this as a cause of revision. Furthermore, confounding variables that may influence the decision of revising a prosthetic hip with recurrent dislocation cannot be completely excluded.

### Effect of lumbar spine fusion on biomechanics

Normal spino-pelvic physiology results in the pelvis tilting anteriorly, lordosis of the lumbar spine and extension of the hip from sitting to standing. This balances the trunk above the pelvis and positions the acetabulum over the femoral head [26]. When sitting, not only does the hip flex, but the pelvis also tilts posteriorly as the spine becomes less lordotic. The posterior tilting increases the anteversion and inclination of the acetabulum, known as the biological opening of the acetabulum, for optimum articulation [20]. Since the spine–pelvic–hip motion is coordinated during postural changes, any previous or concurrent pathology affecting the mobility of one would often affect the other.

Spino-pelvic stiffness can present in two main forms, either as stuck-standing or as stuck-sitting [52]. Stuck-standing refers to excess anterior pelvic tilting and hyper-lordosis of the lumbar spine when sitting. This leads to an increased risk of anterior impingement and possible posterior dislocation of the femoral head in a flexed hip position. Stuck-sitting, on the other hand, refers to excess posterior pelvic tilting and hypo-lordosis of the lumbar spine when standing. This leads to an increased risk of posterior impingement and possible anterior dislocation of the femoral head in an extended hip position [52]. Fusion of a lumbar spine segment could result in hypo-lordosis of the spine, leading to spino-pelvic stiffness in a stuck-sitting phenomenon [4]. This has implications for the spino-pelvic movement mechanism, with a recent study noting that for every 1° of decrease in spino-pelvic motion, there was a 0.9° increase in femoral motion [18]. Clinically, the stuck-sitting phenomenon would lead to a compensatory increase in hip-femoral extension during functional and postural activities such as walking and lying supine. This increases the risk of posterior osseous impingement and subsequent anterior dislocation [25, 26, 52]. A schematic illustration is provided in Fig. 10.

The risk of stuck-sitting spino-pelvic stiffness is also dependent on the amount of lumbar lordosis restoration achieved in spinal fusion surgery. This can be dependent on the surgical technique, approach, implant choices and even the use of osteotomies. Hence, by achieving a greater restoration of lumbar lordotic curvature, there is more anterior pelvic tilt. The result is a less stuck-sitting phenomenon and a higher threshold of femoral range of motion before causing dislocation.

## Hip dislocation

Hip dislocation is not only a major complication of THA but also an indication for revision in cases of recurrent dislocations [8, 55, 58]. Dislocation in THA is a sign of increased instability and can have multiple causes. Impingement is the most common mechanism of hip dislocation [7, 37]. It can be caused by mal-positioning of components, osteophytes, or capsular or scar tissue, leading to a displacement of the femoral head posteriorly or anteriorly [58]. High inclination of more than 60° leads to reduced superior coverage of prosthetic head, whereas low inclination below 30° can lead to lateral impingement in abduction and flexion [58]. A retroverted or neutral cup predisposes to anterior femoral impingement and posterior dislocations when sitting or flexing the hip. Increased anteversion, on the other hand, makes it possible to impinge at the posterior margin, resulting in anterior dislocations.

## Acetabular cup position

Accurate acetabular cup positioning is an important aspect of reducing hip dislocations in these SF patients. Traditionally, the Lewinnek "safe zone" target of 15° ± 10° anteversion and 40° ± 10° inclination has been considered to be the benchmark in order to optimise THA stability [29]. However, a cohort study of 9784 primary THA found a majority (58%) of dislocated THA had a cup placement within the Lewinnek "safe zone" [1]. In conjunction with recent anatomical studies using CT data, it is postulated that the ideal cup position for some patients may lie outside the Lewinneck "safe zone", especially in patients with abnormal pelvic tilt and posture [26, 27]. The transverse acetabular ligament (TAL) has been used as an intra-operative landmark to optimise cup positioning within the Lewinneck "safe zone" as described by several studies [3, 19, 41]. The use of TAL is patient specific and produces consistent results by aligning the inferior cup rim parallel to the TAL or within 5 mm of its margin for optimal anteversion and inclination [19]. However, recent research has demonstrated that TAL alone may no longer be an accurate intra-operative guide for cup positioning in the presence of pelvic tilting [28]. Furthermore, Lembeck [28] has shown that pelvic tilt can cause inaccuracies in cup positioning, with every 1° of pelvic posterior tilt leading to a functional anteversion of the cup by 0.7°. Therefore, this suggests that the dynamic physiological variation in pelvic positions can alter the version of the cup, which affects the stability of the joint.

## Combined version

Apart from cup positioning, femoral version is important for stable articulation of THA and avoids instability or impingement in various body positions [14]. Ranawat [45] defined the range for combined anteversion of the femoral stem and cup as 25°–45°, with 20°–25° of cup anteversion and 10°–15° of femoral anteversion [14, 45]. In SF patients, spino-pelvic stiffness and hypo-lordosis of the spine leads to loss of anterior pelvic tilting, resulting in anteversion of the acetabulum. It is estimated that every 5° loss of anterior tilt results in an increase in anteversion of between 2.5° and 5° [12]. Hence, in order for the combined hip anteversion to fall within the target range, a smaller femoral anteversion has to be accounted for to compensate for the loss of anterior pelvic tilt [14, 39].

Orthopaedic surgeons should be aware of this association and consider modifications to implant positioning by customising acetabular targets that compensate the altered physiological biomechanics of spino-pelvic mobility in these patients [52]. New methods of planning including pre-operative dynamic analysis and positional imaging (standing, sitting and squatting) which may be useful in allowing the surgeon to identify patients with high risks of dislocation [44]. Furthermore, it is thought that patients with altered spino-pelvic biomechanics, such as the SF cohort, could benefit from the use of patient-specific instrumentation, navigation or robotic-assisted surgeries since these techniques have previously been shown to achieve more accurate implant cup positioning [46, 47, 51]. While a recent meta-analysis comparing between robotic-assisted and conventional THA showed that in spite of superior cup positioning alignment accuracy for robotic-assisted THA, the robotic-assisted group paradoxically had a slightly higher dislocation rate than the conventional group, but this was not statistically significant ($p = 0.08$) [11]. Unfortunately, Chen did not provide an explanation for this finding. It thus seems to suggest that while a higher accuracy of implant positioning can be achieved, this "accurate position" may in fact vary between patients, highlighting the importance of patient-specific cup positioning targets instead [1]. However, a recent cohort study investigating the incidence of early dislocation with highly accurate patient-specific cup positioning using imageless navigation did not reveal any significant relationship [34]. As such, these suggestions remain theoretical and have yet to produce any clinical or functional benefits in terms of dislocations or clinical outcome.

## PROM

While meta-analysis was unable to be performed on PROM, individual studies [15, 30, 48, 57] that reported PROM demonstrated an associated overall poorer clinical outcome for THA patients with SF. A recent study by Palazzo [40] suggests that the expectations of patients and their subsequent fulfilment is the strongest predictor of THA satisfaction after 1 year. In addition, amongst the postoperative determinants of expectation fulfilment were functional outcome and pain levels [40]. It is thus possible that the poorer outcomes related to patients with SF may be caused by the presence of more complications such as hip dislocations as well as due to pain and comorbidities associated with degenerative spine disease and previous fusion. Furthermore, the evidence of patients with previous SF having a higher risk of adjacent segment disease in the longer term is well documented [43]. This phenomenon would further reduce lumbar spine range of motion and also cause associated degenerative lumbar spine pain, which further impact on functional outcome scores. It is thus imperative for orthopaedic surgeons to consider previous or concurrent spinal pathologies during preoperative counselling of THA in order to moderate patient expectations and assist in optimising patient satisfaction.

In 2017, Mannion et al. [33] were the first to introduce a common, but joint-specific instrument to report PROM after surgery for degenerative disorders of the spine, hip or knee. They found statistically significant higher odds of achieving a "successful" surgery in hip surgery than in spinal surgery in areas of satisfaction with care, global treatment outcome and patient-acceptable symptom state. Hence, the inherently poorer PROM after spinal surgery could also explain the poorer outcomes associated with THA after spinal fusion.

## Limitations

Due to the lack of randomisation and retrospective nature of studies, selection and recall bias cannot be completely excluded. The use of registry data may also raise concerns with regard to the quality of data, since quality standards have not been well established or consistently reported [17]. Furthermore, the information provided about external validity of registry data is often limited [17]. The doubling effect observed when subgroup analysis of non-registry data was performed suggested a lower rate of detection of complications in registries. We note that the studies included in the review are heterogeneous in terms of study design, and surgical factors such as THA approaches, SF types and levels included. We were unable to adjust our results for significant factors contributing to spino-pelvic stiffness, including the number of fusion levels and the presence of L5–S1 fusion. This is due to the lack of raw data reporting on these factors by individual studies. The lack of a standardised clinical outcome parameter has rendered inadequate raw data for meta-analysis to be performed on clinical outcomes. Hence, the effect of SF on clinical outcomes of THA is still not well established. Furthermore, due to the nature of registry studies, causes for revisions are not specifically documented. Hence, the subgroup analysis of revision solely due to hip dislocations was only performed based on three studies. Despite the usefulness and direct relevance of this subgroup analysis, the numbers involved are small and may not be fully representative of the general population receiving THA.

Furthermore, these studies only investigated the presence of a spinal fusion history as a dichotomous variable with no consideration of the time lapse from spinal fusion to THA. The effect of time between SF and THA should be investigated in future studies, and whether long-term compensatory mechanisms exist to mitigate the effect of lumbar spine fusion on spino-pelvic parameters or whether a longer period of time with altered spino-pelvic and hip biomechanics after spinal fusion could further contribute to poorer outcomes of THA should also be investigated.

## Conclusion

THA patients with SF are at higher risks of hip dislocations, revisions and all complications, which may adversely affect PROM. Surgeons should be aware of these risks and adopt patient-specific planning and implant positioning to reduce the risks of hip dislocations. Other potential strategies to overcome these risks should be further explored.

**Author contributions** JRO contributed to idea conception, literature search, data collection, statistics, manuscript writing and editing. MN contributed to idea conception, manuscript writing and editing. JO contributed to literature search, data collection, statistics, figures and tables, and manuscript writing. KP contributed to statistics, figures and manuscript writing. AA, SB and RH contributed to manuscript writing and editing.

### Compliance with ethical standards

**Conflict of interest** Each author certifies that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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## Affiliations

**James Randolph Onggo[1] · Mithun Nambiar[1,2] · Jason Derry Onggo[1,3] · Kevin Phan[4] · Anuruban Ambikaipalan[1] · Sina Babazadeh[1,5] · Raphael Hau[1,6]**

✉ James Randolph Onggo
jamesonggo1993@hotmail.com

Mithun Nambiar
mithunnambiar1@gmail.com

Jason Derry Onggo
jasononggo@hotmail.com

Kevin Phan
kphan.vc@gmail.com

Anuruban Ambikaipalan
rubanambi@hotmail.com

Sina Babazadeh
sbabazadeh@gmail.com

Raphael Hau
raphaelhau@hotmail.com

1 Department of Orthopaedic Surgery, Box Hill Hospital, Box Hill, VIC, Australia

2 Department of Surgery, The University of Melbourne, Parkville, VIC, Australia

3 School of Medicine, Flinders University, Adelaide, SA, Australia

4 NeuroSpine Research Group, Sydney, NSW, Australia

5 Department of Orthopaedic Surgery, St Vincent's Hospital, East Melbourne, VIC, Australia

6 Epworth Eastern Hospital, Box Hill, VIC, Australia