Unilateral versus bilateral pedicle screw fixation in lumbar fusion: A systematic review of overlapping meta-analyses

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Abstract

Objectives
To carry out a systematic review on the basis of overlapping meta-analyses that compare unilateral with bilateral pedicle screw fixation (PSF) in lumbar fusion to identify which study represents the current best evidence, and to provide recommendations of treatment on this topic.

Methods
A comprehensive literature search in PubMed, Embase, and the Cochrane Library databases was conducted to identify meta-analyses that compare unilateral with bilateral PSF in lumbar fusion. Only meta-analyses exclusively covering randomized controlled trials were included. Study quality was evaluated using the Oxford Levels of Evidence and Assessment of Multiple Systematic Reviews (AMSTAR) instrument. Then, the Jadad decision algorithm was applied to select the highest-quality study to represent the current best evidence.

Results
A total of 9 studies with Level II of evidence fulfilled the eligibility criteria and were included. The scores of AMSTAR criteria for them varied from 5 to 9 (mean 7.78). The current best evidence detected no significant differences between unilateral and bilateral PSF for short-segment lumbar fusion in the functional scores, length of hospital stay, fusion rate, and complication rate. However, unilateral PSF involved a remarkable decrease in operative time and blood loss but increase of cage migration when compared with bilateral PSF.

Conclusions
According to this systematic review, unilateral PSF is an effective method of fixation for short-segment lumbar fusion, has the advantages of reduced operative time and blood loss over bilateral PSF, but increases the risk of cage migration.
Introduction

Lumbar fusion is an effective procedure commonly performed for treating lumbar degenerative disc diseases [1]. Generally, bilateral pedicle screw fixation (PSF) is deemed a standard instrumentation for lumbar fusion. However, the pronounced stiffness of bilateral PSF appears to cause undesired adverse effects such as reduced fusion rate, adjacent segment degeneration, and loss of bone mineral content [2,3]. In response to those concerns, unilateral PSF, which involves less rigidity, has been developed for lumbar fusion.

Biomechanical studies have demonstrated that unilateral PSF is able to maintain the initial stability after lumbar fusion, and decrease the influence of stress-shielding imposed on the fixed level and levels adjacent to the fusion [4,5]. In addition, numerous clinical studies have suggested that unilateral PSF is as effective as bilateral PSF for lumbar fusion but has the advantages of reduced operation time, blood loss, and implant cost [6–14]. A 5-year follow-up study by Toyone et al. [15] also found a lower occurrence of adjacent segment degeneration in patients undergoing unilateral PSF than that in patients who underwent bilateral PSF. Reversely, there exist studies indicating that unilateral PSF provided less stability than did bilateral PSF for lumbar fusion [16–20]. Due to its inherent asymmetry and reduced strength, unilateral PSF was reported to cause postoperative back pain, implant failure, more cage migration, and a relatively lower fusion rate when compared with bilateral PSF [8,21–23].

Recently, multiple meta-analyses have carried out a comparison of unilateral and bilateral PSF in lumbar fusion. However, those overlapping meta-analyses showed discordant results as well. Several studies suggested that unilateral and bilateral PSF were equally safe and effective for lumbar fusion [24–28]. However, the results of other studies indicated that unilateral PSF lead to more cage migration or a relatively lower fusion rate than bilateral PSF [29–33]. As a result, the above conflicting findings may bring uncertainty about which method of fixation is better for lumbar fusion.

The objectives of this study were to carry out a systematic review on the basis of overlapping meta-analyses regarding unilateral versus bilateral PSF in lumbar fusion to provide recommendations of treatment on this topic according to the current best evidence, and to identify potential limitations within current literature that require future research.

Materials and methods

We carried out this systematic review according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement [34]. Ethical approval or patient consent is not required for this review.

Literature search

A comprehensive literature search was carried out on July 27, 2019 using PubMed, Embase, and the Cochrane Library databases. The following keywords were adopted: unilateral, bilateral, lumbar, fusion, arthrodesis, systematic review, meta-analysis. Two reviewers independently performed the literature search. We first reviewed the titles and abstracts of all articles, and then obtained the full texts of articles that met the inclusion criteria. To identify other potentially eligible articles, the references were manually retrieved and screened as well. Disagreements were discussed and settled by consensus. Full electronic search strategy for PubMed: ((unilateral) OR bilateral) AND lumbar AND ((fusion) OR arthrodesis) AND ((systematic review) OR meta-analysis).

Eligibility criteria

Inclusion criteria were listed as follow: (1) meta-analysis that compares unilateral and bilateral PSF in lumbar fusion; (2) inclusion of randomized controlled trials (RCTs) exclusively; (3)
report of at least 1 outcome (functional scores, fusion rate, operation time, blood loss, complication rate, cage migration and so on); (4) English-language article. Correspondence, narrative reviews, annual meeting abstracts, systematic reviews without a meta-analysis or data pooling, and meta-analyses with no outcome data or including non-RCTs were excluded. In addition, the animal, cadaveric, and other non-clinical studies were also excluded.

Data extraction

From each included study, the following data were extracted by two reviewers independently: first author, date of last literature search, publication journal and date, numbers of RCTs included, inclusion/exclusion criteria, restrictions to publication status and language, search databases, level of evidence, primary study design, software used for data analysis, whether sensitivity or subgroup analysis, Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system, and publication bias were performed, conflict of interest, I² statistic value of variables in each meta-analysis. In addition, clinical outcome data were also extracted, including the fusion rate, functional scores, operative time, length of hospital stay, blood loss, implant cost, nonunion rate, reoperation rate, total complication, general complication, infection, dura tear, implant-related complication, screw complication, and the cage migration. Disagreements were discussed and settled by consensus.

Quality assessment

Methodological information of each included study was evaluated via the Oxford Levels of Evidence [35,36]. Furthermore, the Assessment of Multiple Systematic Reviews (AMSTAR) instrument was used to evaluate the study quality as well, which is a tool applied to methodological evaluation of meta-analyses and systematic reviews with good validity, reliability, and responsibility [37–39]. In this review, two reviewers evaluated the methodological quality of each included study independently. Disagreements were discussed and settled by consensus.

Heterogeneity assessment

The heterogeneity across studies was evaluated using the I² statistic which is a quantitative measurement to investigate inter-study variability. When I² value > 50%, heterogeneity is deemed to exist between studies. If so, two reviews evaluated whether sensitivity or subgroup analysis was carried out to assess the robustness of data pooled and explore the potential causes of heterogeneity.

Application of Jadad decision algorithm

The Jadad decision algorithm was applied to interpret discordant findings among meta-analyses. The possible causes of discordance, as mentioned by Jadad et al. [40], include different study question, inclusion/exclusion criteria, quality assessment, data pooling and extraction, and statistical analysis. Currently, this algorithm is widely used for providing treatment recommendations among conflicting meta-analyses on certain topics [41–45]. Two reviewers independently ran this algorithm, and then a consensus was reached as to which meta-analysis represents the current best evidence.

Results

Literature search

Fig 1 displayed the flowchart of study screening. The initial literature search identified 88 articles. After screening, 9 meta-analyses met the eligibility criteria and were finally included in
This systematic review [27–29,33,46–50]. Those overlapping meta-analyses were published between 2014 and 2018 but in different journals, and the numbers of included RCTs among them ranged from 3 to 12 (Table 1). As shown in Table 2, the publication years of primary RCTs were between 2007 and 2015.
Although the studies here conducted a comprehensive literature search, the search databases were discordant among them. All studies searched PubMed or Medline database. Of the 9 included studies, 7 searched Embase, 8 searched the Cochrane Library, whereas Web of Science, Ovid, Springer, CINAHL, Current Controlled Trials, National Guideline Clearing-house, and other databases were retrieved in different studies. In addition, the restriction of

Table 1. Characteristics of each included study.

| Author       | (Year) | Publication Date | Publication Journal | Last Literature Search Date | No. of RCTs Included |
|--------------|--------|------------------|---------------------|----------------------------|---------------------|
| Hu XQ        | [50]   | January, 2014    | PLoS One            | August, 2013               | 7                   |
| Yuan C       | [29]   | February, 2014   | Clinical Neurology and Neurosurgery | NA | 7 |
| Wang L       | [49]   | November, 2014   | BMC Surgery         | December, 2013             | 3                   |
| Molinari RW  | [48]   | June, 2015       | Global Spine Journal | September, 2014          | 10                  |
| Li X         | [47]   | March, 2015      | Medical Science Monitor | July, 2014               | 10                  |
| Xiao SW      | [46]   | April, 2015      | European Spine Journal | June, 2014               | 8                   |
| Ren S        | [27]   | January, 2016    | International Journal of Clinical and Experimental Medicine | April, 2016 | 12 |
| Xin Z        | [28]   | February, 2016   | International Orthopaedics | April, 2015          | 11                  |
| Lu P         | [33]   | November, 2018   | Journal of Orthopaedic Surgery and Research | August, 2018 | 12 |

NA, not available; RCTs, randomized controlled trials.

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Search methodology

Although the studies here conducted a comprehensive literature search, the search databases were discordant among them. All studies searched PubMed or Medline database. Of the 9 included studies, 7 searched Embase, 8 searched the Cochrane Library, whereas Web of Science, Ovid, Springer, CINAHL, Current Controlled Trials, National Guideline Clearing-house, and other databases were retrieved in different studies. In addition, the restriction of

Table 2. Primary trials included in each study.

| Author       | (Year) | Fernández-Fairen (2007) | Feng (2011) | Lin (2012) | Aoki (2012) | Xie (2012) | Xue (2012) | Dahdaleh (2013) | Choi (2013) | Duncan (2013) | Lin (2013) | Shen (2013) | Zhang (2014) | Shen (2014) | Dong (2014) | Gu (2015) |
|--------------|--------|------------------------|-------------|------------|-------------|------------|------------|-----------------|-------------|--------------|------------|-------------|--------------|-------------|-------------|-----------|
| Hu XQ        | (2014) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Yuan C       | (2014) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Wang L       | (2014) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Molinari RW  | (2015) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Li X         | (2015) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Xiao SW      | (2015) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Ren S        | (2016) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Xin Z        | (2016) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |
| Lu P         | (2018) | +                      | +           | +          | +           | +          | +          | +               | +           | +            | +          |             |              |             |             |           |

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publication language and status was discordant as well. Of the 9 studies, 4 only included articles published in English [29,46,47,50], 1 included both English- and Chinese-languages articles [28], 3 had no linguistic restriction [27,33,49], and the remaining 1 did not refer to restriction of publication language [48]. Only 1 study disclosed that unpublished data were reviewed [47], 1 study did not review unpublished data [50], and the remaining studies did not refer to restriction of publication status [27–29,33,46,48,49]. Details of search methodology applied by the included studies were presented in Table 3.

### Methodological quality

Based on the Oxford Levels of Evidence, we determined each study, which covers only RCTs, to be Level II of evidence (Table 4). Of the 9 included studies, 8 used RevMan for data analyses [27–29,46–50], only 1 used the Stata software [33]. In addition, 3 studies adopted the GRADE system [28,33,48], 7 studies conducted the sensitivity and/or subgroup analyses [27–29,33,46,48,50], and 4 studies assessed the possibility of publication bias [27,33,47,50]. As shown in Table 5, the scores of AMSTAR criteria for included studies varied from 5 to 9 (mean 7.78). Finally, the meta-analysis by Lu et al. [33], with an AMSTAR score of 9, was chosen as the highest-quality study.

### Heterogeneity assessment

All included studies assessed the heterogeneity using the $I^2$ statistic (Table 6). No or slight heterogeneity was found in the fusion rate, nonunion rate, reoperation rate, total complication,
general complication, infection, dura tear, implant-related complication, cage migration, and screw complication. Nevertheless, the heterogeneity of operation time, blood loss, and length of hospital stay was very large. There also existed different levels of heterogeneity in the functional outcomes. To further explore the potential sources of heterogeneity, 7 studies performed the sensitivity and/or subgroup analyses [27–29,33,46,48,50], as shown in Table 4.

Results of Jadad decision algorithm

Fig 2 showed the pooled results of each meta-analysis. The Jadad decision algorithm was adopted to identify which study represents the current best evidence to provide treatment recommendations. Considering that the 9 included meta-analyses focused on the same clinical question while they did not cover the same primary trials and criteria of study selection, the highest-quality study can be selected based on the methodological quality and publication status of primary trials, language restrictions, and data analysis on individual patients (Fig 3). Eventually, the meta-analysis by Lu et al. [33] was identified as the highest-quality study with more RCTs using the Jadad decision algorithm. This study detected no significant differences between unilateral and bilateral PSF for lumbar fusion in the functional scores, length of hospital stay, fusion rate, and complication rate. However, unilateral PSF significantly reduced the operative time and blood loss but increased cage migration when compared with bilateral PSF.

Discussion

Currently, numerous RCTs have made a comparison of unilateral and bilateral PSF in lumbar fusion, whereas their findings are conflicting as to which method of fixation is better [6–13,21,23,51–54]. To further clarify this issue, multiple meta-analyses based on RCTs, which provide the highest level of evidence, have also compared the two fixation methods for lumbar fusion [27–29,33,46–50]. Nevertheless, the results are discordant as well. Recently, several systematic reviews have been conducted based on overlapping meta-analyses [41–45], which can provide information that may assist decision makers in choosing the highest-quality study among meta-analyses with discordant findings.

The objectives of this study were to carry out a systematic review on the basis of overlapping meta-analyses based on RCTs regarding unilateral versus bilateral PSF in lumbar fusion to identify which study represents the highest level of evidence to provide treatment recommendations on this topic. After a comprehensive literature search, 9 meta-analyses were finally included in this review [27–29,33,46–50]. Jadad et al. [40] designed a decision tool to allow...
selection of the highest-quality study from among conflicting meta-analyses, which has been widely used in medical fields [41–45]. Finally, the meta-analysis by Lu et al. [33], which included the most RCTs with Level II of evidence, was chosen as the highest-quality study based on the Jadad decision algorithm. The current best evidence detected no obvious differences between the two fixation methods for lumbar fusion in functional scores, length of hospital stay, fusion rate, and complication rate. Furthermore, unilateral PSF was superior to bilateral PSF in operation time and blood loss, but increased cage migration. Based on the above findings, Lu et al. [33] concluded that unilateral PSF is recommended as the optimal fixation method for lumbar fusion.

Interestingly, the 9 included studies were published within the last few years and focused on the same study question, whereas they did not cover the same primary RCTs and criteria of study selection [27–29,33,46–50]. As a result, findings were discordant regarding unilateral versus bilateral PSF in lumbar fusion. According to this review, no significant differences were detected between the two fixation methods for lumbar fusion in functional scores, length of hospital stay, fusion rate, and complication rate. Furthermore, unilateral PSF was superior to bilateral PSF in operation time and blood loss, but increased cage migration. Based on the above findings, Lu et al. [33] concluded that unilateral PSF is recommended as the optimal fixation method for lumbar fusion.

With regard to surgical trauma, 6 studies showed that unilateral PSF significantly reduced the operative time and/or blood loss in comparison with bilateral PSF for lumbar fusion [27,28,33,47,49,50]. While no remarkable difference was detected in blood loss, the study by Xiao et al. [46] also reported data favoring unilateral PSF. In addition, unilateral PSF achieved a similar hospital stay with bilateral PSF, despite the fact that lesser dissection of soft tissues benefits functional recovery. Although there was large heterogeneity across studies, which was associated with type of operation, surgical segments, or skill of the surgeons, the current

Table 5. AMSTAR criteria for each study.

| Items                                                                 | Hu XQ [50] (2014) | Yuan C [29] (2014) | Wang L [49] (2014) | Molinari RW [48] (2015) | Li X [47] (2015) | Xiao SW [46] (2015) | Ren S [27] (2016) | Xin Z [28] (2016) | Lu P [33] (2018) |
|-----------------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------|------------------|--------------------|-------------------|-------------------|------------------|
| 1. Was an a priori design provided?                                    | 0                  | 0                  | 0                  | 0                      | 0                | 0                  | 0                 | 0                 | 0                |
| 2. Were there duplicate study selection and data extraction?           | 1                  | 1                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 3. Was a comprehensive literature search performed?                   | 1                  | 0                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 4. Was the status of publication (i.e. grey literature) used as an inclusion criterion? | 0                  | 0                  | 0                  | 0                      | 1                | 0                  | 0                 | 0                 | 0                |
| 5. Was a list of studies (included and excluded) provided?            | 0                  | 0                  | 0                  | 1                      | 0                | 1                  | 1                 | 0                 | 1                |
| 6. Were the characteristics of the included studies provided?          | 1                  | 1                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 7. Was the scientific quality of the included studies assessed and documented? | 1                  | 1                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 8. Was the scientific quality of the included studies used appropriately in formulating conclusions? | 1                  | 1                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 9. Were the methods used to combine the findings of studies appropriate? | 1                  | 1                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| 10. Was the likelihood of publication bias assessed?                   | 1                  | 0                  | 0                  | 0                      | 1                | 0                  | 1                 | 0                 | 1                |
| 11. Was the conflict of interest stated?                               | 1                  | 0                  | 1                  | 1                      | 1                | 1                  | 1                 | 1                 | 1                |
| Total scores                                                          | 8                  | 5                  | 7                  | 8                      | 9                | 8                  | 9                 | 7                 | 9                |

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evidence concluded that unilateral PSF was superior to bilateral PSF in operation time and blood loss due to its not dissecting the soft tissues on the contralateral side.

Despite unilateral PSF was reported to cause adverse effects due to its inherent asymmetry and reduced stability [8,21–23], no significant differences were detected between them for lumbar fusion in the fusion rate, nonunion rate, reoperation rate, general complication, and total complication according to this review. With respect to implant-related complications, 5 studies found no significant differences between the two methods [27,28,46–48]. Of the 4 studies that reported data of cage migration, 2 detected no significant differences but an increased incidence in patients undergoing unilateral PSF [46,48], the other 2, including the highest-quality study, favored bilateral PSF [29,33]. Risk factors for cage migration are multiple such as cage type, cage position, cage material, cage size, disc space shape, multilevel fusion, degenerative scoliosis, and unilateral PSF [55–59]. The increased cage migration in patients who underwent unilateral PSF may be caused by inherent asymmetry that results in asymmetry. No or slight heterogeneity exists between studies in the above outcomes. To sum up, the current evidence demonstrated that unilateral PSF increased the risk of cage migration in lumbar fusion when compared with bilateral PSF.

This study had several limitations. First, only articles that published in English were included. Non-English articles meeting the eligibility criteria may have been excluded. Second,
A meta-analysis that covers only RCTs was identified as Level II of evidence. Therefore, we cannot provide treatment recommendations on this topic based on Level I of evidence. Third, none of the primary trials had data for more than 5 years. Long-term follow up is required to further verify these findings. Fourth, the current literature mainly focused on comparing unilateral and bilateral PSF in short-segment lumbar fusion. A comparison of them in long-segment lumbar fusion could not be made. Last but not least, this review may be underpowered by other potential limitations and bias within the included meta-analyses and primary trials.

Conclusions

This is the first systematic review on the basis of overlapping meta-analyses to analyze unilateral versus bilateral PSF in lumbar fusion. According to the current best evidence, no significant differences were detected between unilateral and bilateral PSF for short-segment lumbar fusion in functional scores, length of hospital stay, fusion rate, and complication rate. However, unilateral PSF involved a remarkable decrease in operative time and blood loss but increase of cage migration when compared with bilateral PSF. In conclusion, unilateral PSF is an effective method of fixation for short-segment lumbar fusion, has the advantages of reduced operative time and blood loss over bilateral PSF, but increases the risk of cage migration.
Supporting information

S1 File. PRISMA checklist.

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References

1. Deyo RA, Nachemson A, Mirza SK. Spinal-fusion surgery—the case for restraint. N Engl J Med. 2004; 350(7):722–6. https://doi.org/10.1056/NEJMsb031771 PMID: 14960750
2. McAfee PC, Farey ID, Sutterlin CE, Gurr KR, Warden KE, Cunningham BW. 1989 Volvo Award in basic science. Device-related osteoporosis with spinal instrumentation. Spine (Phila Pa 1976). 1989; 14 (9):919–26.

3. Lee CS, Hwang CJ, Lee SW, Ahn YJ, Kim YT, Lee DH, et al. Risk factors for adjacent segment disease after lumbar fusion. Eur Spine J. 2009; 18(11):1637–43. https://doi.org/10.1007/s00586-009-1060-3 PMID: 19533182

4. Goel VK, Lim TH, Gwon J, Chen JY, Winterbottom JM, Park JB, et al. Effects of rigidity of an internal fixation device. A comprehensive biomechanical investigation. Spine (Phila Pa 1976). 1991; 16(3 Suppl): S155–61.

5. Chen HH, Cheung HH, Wang WK, Li A, Li KC. Biomechanical analysis of unilateral fixation with interbody cages. Spine (Phila Pa 1976). 2005; 30(4):E92–6.

6. Lin B, Lin QY, He MC, Liu H, Guo ZM, Lin KS. Clinical study on unilateral pedicle screw fixation and interbody fusion for the treatment of lumbar degenerative diseases under Quadrant system. Zhongguo Gu Shang. 2012; 25(6):468–73. PMID: 23016381

7. Xie Y, Ma H, Li H, Ding W, Zhao C, Zhang P, et al. Comparative study of unilateral and bilateral pedicle screw fixation in posterior lumbar interbody fusion. Orthopedics. 2012; 35(10):e1517–23. https://doi.org/10.3928/01477447-20120919-22 PMID: 23027490

8. Xue H, Tu Y, Cai M. Comparison of unilateral versus bilateral instrumented transforaminal lumbar interbody fusion in degenerative lumbar diseases. Spine J. 2012; 12(3):209–15. https://doi.org/10.1016/j.spinee.2012.01.010 PMID: 22381573

9. Dahdahle NS, Nixon AT, Lawton CD, Wong AP, Smith ZA, Fessier RG. Outcome following unilateral versus bilateral instrumentation in patients undergoing minimally invasive transforaminal lumbar interbody fusion: a single-center randomized prospective study. Neurosurg Focus. 2013; 35(2):E13. https://doi.org/10.3171/2013.5.FOCUS13171 PMID: 23905951

10. Lin B, Xu Y, He Y, Zhang B, Lin Q, He M. Minimally invasive unilateral pedicle screw fixation and lumbar fusion for the treatment of lumbar degenerative disease. Orthopedics. 2013; 36(8):e1071–6. https://doi.org/10.3928/01477447-20130724-26 PMID: 23937756

11. Zhang K, Sun W, Zhao CQ, Li H, Ding W, Xie YZ, et al. Unilateral versus bilateral instrumented transforaminal lumbar interbody fusion in two-level degenerative lumbar disorders: a prospective randomised study. Int Orthop. 2014; 38(1):111–6. https://doi.org/10.1007/s00264-013-2026-y PMID: 23917853

12. Shen X, Zhang H, Gu X, Gu G, Zhou X, He S. Unilateral versus bilateral pedicle screw instrumentation for single-level minimally invasive transforaminal lumbar interbody fusion. J Clin Neurosci. 2014; 21(9):1612–6. https://doi.org/10.1016/j.jocn.2013.11.055 PMID: 24814852

13. Dong J, Rong L, Feng F, Liu B, Xu Y, Wang Q, et al. Unilateral pedicle screw fixation through a tubular retractor via the Wiltse approach compared with conventional bilateral pedicle screw fixation for single-segment degenerative lumbar instability: a prospective randomized study. J Neurosurg Spine. 2014; 20(1):53–9. https://doi.org/10.3171/2013.9.SPINE1392 PMID: 24236667

14. Gu G, Zhang H, Fan G, He S, Meng X, Gu X, et al. Clinical and radiological outcomes of unilateral versus bilateral instrumentation in two-level degenerative lumbar diseases. Eur Spine J. 2015; 24(8):1640–8. https://doi.org/10.1007/s00586-015-4031-x PMID: 26002354

15. Toyone T, Ozawa T, Kamikawa K, Watanabe A, Matsuki K, Yamashita T, et al. Subsequent vertebral fractures following spinal fusion surgery for degenerative lumbar diseases: a mean ten-year follow-up. Spine (Phila Pa 1976). 2010; 35(21):1915–8.

16. Harris BM, Hillbrand AS, Savas PE, Pellegrino A, Vaccaro AR, Siegler S, et al. Transforaminal lumbar interbody fusion: the effect of various instrumentation techniques on the flexibility of the lumbar spine. Spine (Phila Pa 1976). 2004; 29(4):E65–70.

17. Slucky AV, Brodkle DS, Bachus KN, Droge JA, Braun JT. Less invasive posterior fixation method following transforaminal lumbar interbody fusion: a biomechanical analysis. Spine J. 2006; 6(1):78–85. https://doi.org/10.1016/j.spinee.2005.08.003 PMID: 16413452

18. Yucesoy K, Yuksel KZ, Baek S, Sonntag VK, Crawford NR. Biomechanics of unilateral compared with bilateral lumbar pedicle screw fixation for stabilization of unilateral vertebral disease. J Neurosurg Spine. 2008; 8(1):44–51. https://doi.org/10.3171/SPI-08/01/044 PMID: 18173346

19. Sethi A, Muzumdar AM, Ingalhalikar A, Vaidya R. Biomechanical analysis of a novel posterior construct in a transforaminal lumbar interbody model an in vitro study. Spine J. 2011; 11(9):863–9. https://doi.org/10.1016/j.spinee.2011.06.015 PMID: 21802998

20. Chen SH, Lin SC, Tsai WC, Wang CW, Chao SH. Biomechanical comparison of unilateral and bilateral pedicle screws fixation for transforaminal lumbar interbody fusion after decompressive surgery—a finite element analysis. BMC Musculoskelet Disord. 2012; 13:72. https://doi.org/10.1186/1471-2474-13-72 PMID: 22591664
21. Aoki Y, Yamagata M, Ikeda Y, Nakajima F, Ohtori S, Nakagawa K, et al. A prospective randomized controlled study comparing transforminal lumbar interbody fusion techniques for degenerative spondylolisthesis: unilateral pedicle screw and 1 cage versus bilateral pedicle screws and 2 cages. J Neurosurg Spine. 2012; 17(2):153–9. https://doi.org/10.3171/2012.5.SPINE111044 PMID: 22702892

22. Mao L, Chen GD, Xu XM, Guo Z, Yang HL. Comparison of lumbar interbody fusion performed with unilateral or bilateral pedicle screw. Orthopedics. 2013; 36(4):e489–93. https://doi.org/10.3928/01477447-20130327-28 PMID: 23590791

23. Duncan JW, Bailey RA. An analysis of fusion cage migration in unilateral and bilateral fixation with transforminal lumbar interbody fusion. Eur Spine J. 2013; 22(2):439–45. https://doi.org/10.1007/s00586-012-2458-x PMID: 22878377

24. Luo J, Gong M, Gao M, Huang S, Yu T, Zou X. Both unilateral and bilateral pedicle screw fixation are effective for lumbar spinal fusion: A meta-analysis-based systematic review. Journal of Orthopaedic Translation. Orthop. Transl. 2014; 2(2):66–74.

25. Liu Z, Fei Q, Wang B, Lv P, Chi C, Yang Y, et al. A meta-analysis of unilateral versus bilateral pedicle screw fixation in minimally invasive lumbar interbody fusion. PLoS One. 2014; 9(11):e111979. https://doi.org/10.1371/journal.pone.0111979 PMID: 25375315

26. Phan K, Leung V, Scherman DB, Tan AR, Rao PJ, Mobbs RJ. Bilateral versus unilateral instrumentation in spinal surgery: Systematic review and trial sequential analysis of prospective studies. J Clin Neurosci. 2016; 30:15–23. https://doi.org/10.1016/j.jocn.2016.01.013 PMID: 27068653

27. Ren S, Hu Y. Comparison of unilateral versus bilateral pedicle screw fixation in transforminal lumbar interbody fusion: A systematic review and meta-analysis of twelve randomized controlled trials. Int J Clin Exp Med. 2016; 9(9):17113–27.

28. Xin Z, Li W. Unilateral versus bilateral pedicle screw fixation in short-segment lumbar spinal fusion: a meta-analysis of randomised controlled trials. Int Orthop. 2016; 40(2):355–64. https://doi.org/10.1007/s00264-015-2842-3 PMID: 26174053

29. Yuan C, Chen K, Zhang H, Zhang H, He S. Unilateral versus bilateral pedicle screw fixation in lumbar interbody fusion: a meta-analysis of complication and fusion rate. Clin Neurol Neurosurg. 2014; 117:28–32. https://doi.org/10.1016/j.clineuro.2013.11.016 PMID: 24438800

30. Han YC, Liu ZQ, Wang SJ, Li LJ, Tan J. Comparison of unilateral versus bilateral pedicle screw fixation in degenerative lumbar diseases: a meta-analysis. Eur Spine J. 2014; 23(5):974–84. https://doi.org/10.1007/s00586-014-3221-2 PMID: 24549387

31. Cheriyan T, Lafage V, Bendo JA, Spivak JM, Goldstein JA, Errico TJ. Complications of unilateral versus bilateral instrumentation in transforminal lumbar interbody fusion: A meta-analysis. Spine J. 2015; 15(10):191S.

32. Ren C, Qin R, Sun P, Wang P. Effectiveness and safety of unilateral pedicle screw fixation in transforminal lumbar interbody fusion (TLIF): a systematic review and meta-analysis. Arch Orthop Trauma Surg. 2017; 137(4):441–50. https://doi.org/10.1007/s00402-017-2641-y PMID: 28188642

33. Lu P, Pan T, Dai T, Chen G, Shi KQ. Is unilateral pedicle screw fixation superior than bilateral pedicle screw fixation for lumbar degenerative diseases: a meta-analysis. J Orthop Surg Res. 2018; 13(1):296. https://doi.org/10.1186/s13018-018-1004-x PMID: 30466462

34. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009; 6(7):e1000100. https://doi.org/10.1371/journal.pmed.1000100 PMID: 19621079

35. Wright JG, Swiontkowski MF, Heckman JD. Introducing levels of evidence to the journal. J Bone Joint Surg Am. 2003; 85-A(1):1–3.

36. Slobogean G, Bhandari M. Introducing levels of evidence to the Journal of Orthopaedic Trauma: implementation and future directions. J Orthop Trauma. 2012; 26(3):127–8. https://doi.org/10.1097/BOT.0b013e318247c931 PMID: 22330974

37. Shea BJ, Grimshaw JM, Wells GA, Boers M, Andersson N, Hamel C, et al. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. BMC Med Res Methodol. 2007; 7:10. https://doi.org/10.1186/1471-2288-7-10 PMID: 17302989

38. Shea BJ, Bouter LM, Peterson J, Boers M, Andersson N, Ortiz Z, et al. External validation of a measurement tool to assess systematic reviews (AMSTAR). PLoS One. 2007; 2(12):e1350. https://doi.org/10.1371/journal.pone.0001350 PMID: 18159233

39. Shea BJ, Hamel C, Wells GA, Bouter LM, Kristjansson E, Grimshaw J, et al. AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. J Clin Epidemiol. 2009; 62(10):1013–20. https://doi.org/10.1016/j.jclinepi.2008.10.009 PMID: 19230606
40. Jadad AR, Cook DJ, Browman GP. A guide to interpreting discordant systematic reviews. CMAJ. 1997; 156(10):1411–6. PMID: 9164400

41. Mascarenhas R, Chalmers PN, Sayegh ET, Bhandari M, Verma NN, Cole BJ, et al. Is double-row rotator cuff repair clinically superior to single-row rotator cuff repair: a systematic review of overlapping meta-analyses. Arthroscopy. 2014; 30(9):1156–65. https://doi.org/10.1016/j.arthro.2014.03.015 PMID: 24821226

42. Li Q, Wang C, Huo Y, Jia Z, Wang X. Minimally invasive versus open surgery for acute Achilles tendon rupture: a systematic review of overlapping meta-analyses. J Orthop Surg Res. 2016; 11(1):65. https://doi.org/10.1186/s13018-016-0401-2 PMID: 27266275

43. Ding F, Jia Y, Zhao Z, Xie L, Gao X, Ma D, et al. Total disc replacement versus fusion for lumbar degenerative disc disease: a systematic review of overlapping meta-analyses. Eur Spine J. 2017; 26(3):806–15. https://doi.org/10.1007/s00586-016-4714-y PMID: 27448810

44. Tan G, Li F, Zhou D, Cai X, Huang Y, Liu F. Unilateral versus bilateral percutaneous balloon kyphoplasty for osteoporotic vertebral compression fractures: A systematic review of overlapping meta-analyses. Medicine (Baltimore). 2018; 97(33):e11968.

45. Fu BS, Jia HL, Zhou DS, Liu FX. Surgical and Non-Surgical Treatment for 3-Part and 4-Part Fractures of the Proximal Humerus: A Systematic Review of Overlapping Meta-Analyses. Orthop Surg. 2019; 11(3):356–65. https://doi.org/10.1111/os.12486 PMID: 31071336

46. Xiao SW, Jiang H, Yang LJ, Xiao ZM. Comparison of unilateral versus bilateral pedicle screw fixation with cage fusion in degenerative lumbar diseases: a meta-analysis. Eur Spine J. 2015; 24(4):764–74. https://doi.org/10.1007/s00586-014-3717-9 PMID: 25510516

47. Li X, Lv C, Yan T. Unilateral versus bilateral pedicle screw fixation for degenerative lumbar diseases: a meta-analysis of 10 randomized controlled trials. Med Sci Monit. 2015; 21:782–90. https://doi.org/10.12659/MSM.892593 PMID: 25774950

48. Molinari RW, Saleh A, Molinari RJ, Hermmsmeyer J, Dettoi JR. Unilateral versus Bilateral Instrumentation in Spinal Surgery: A Systematic Review. Global Spine J. 2015; 5(3):185–94. https://doi.org/10.1055/s-0035-1552986 PMID: 26131385

49. Wang L, Wang Y, Li Z, Yu B, Li Y. Unilateral versus bilateral pedicle screw fixation of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF): a meta-analysis of randomized controlled trials. BMC Surg. 2014; 14:87. https://doi.org/10.1186/1471-2482-14-87 PMID: 25378083

50. Hu XQ, Wu XL, Xu C, Zheng XH, Jin YL, Wu LJ, et al. A systematic review and meta-analysis of unilateral versus bilateral pedicle screw fixation in transforaminal lumbar interbody fusion. PLoS One. 2014; 9(1):e87501. https://doi.org/10.1371/journal.pone.0087501 PMID: 24489929

51. Choi UY, Park JY, Kim KH, Kuh SU, Chin DK, Kim KS, et al. Unilateral versus bilateral percutaneous pedicle screw fixation in minimally invasive transforaminal lumbar interbody fusion. Neurosurg Focus. 2013; 35(2):E11. https://doi.org/10.3171/2013.2.FOCUS12398 PMID: 23905949

52. Fernandez-Fairen M, Sala P, Ramirez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine (Phila Pa 1976). 2007; 32(4):395–401.

53. Feng ZZ, Cao YW, Jiang C, Jiang XX. Short-term outcome of bilateral decompression via a unilateral paramedian approach for transforaminal lumbar interbody fusion with unilateral pedicle screw fixation. Orthopedics. 2011; 34(5):364. https://doi.org/10.3928/01477447-20110317-05 PMID: 21598901

54. Shen X, Wang L, Zhang H, Gu X, Gu G, He S. Radiographic Analysis of One-level Minimally Invasive Transforaminal Lumbar Interbody Fusion (MI-TLIF) With Unilateral Pedicle Screw Fixation for Lumbar Degenerative Diseases. Clin Spine Surg. 2016; 29(1):E1–8. https://doi.org/10.1097/BSD.0000000000000042 PMID: 24189485

55. Abbushi A, Cabraja M, Thomale UW, Woiciechowsky C, Kroppenstedt SN. The influence of cage positioning and cage type on cage migration and fusion rates in patients with monosegmental posterior lumbar interbody fusion and posterior fixation. Eur Spine J. 2009; 18(11):1621–8. https://doi.org/10.1007/s00586-009-1036-3 PMID: 19475436

56. Smith AJ, Arginteau M, Moore F, Steinberger A, Camins M. Increased incidence of cage migration and nonunion in instrumented transforaminal lumbar interbody fusion with bioabsorbable cages. J Neurosurg Spine. 2010; 13(3):388–93. https://doi.org/10.3171/2010.3.SPINE09587 PMID: 20809735

57. Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Shimizu K, Yoshihara M, et al. Examining risk factors for posterior migration of fusion cages following transforaminal lumbar interbody fusion: a possible limitation of unilateral pedicle screw fixation. J Neurosurg Spine. 2010; 13(3):381–7. https://doi.org/10.3171/2010.3.SPINE09590 PMID: 20809734

58. Kimura H, Shikata J, Odate S, Soeda T, Yamamura S. Risk factors for cage retropulsion after posterior lumbar interbody fusion: analysis of 1070 cases. Spine (Phila Pa 1976). 2012; 37(13):1164–9.
Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Takahashi K. Posterior migration of fusion cages in degenerative lumbar disease treated with transforaminal lumbar interbody fusion: a report of three patients. Spine (Phila Pa 1976). 2009; 34(1):E54–8.