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Robotic Pedicle Screw Placement: A Shortcut to Accurate Stabilization

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ABSTRACT

Introduction: Incorrect placement of traditional freehand pedicle screws may result in dural rupture, nerve damage, and other issues. Robot-assisted pedicle screw insertion has significantly evolved in recent years. However, there were still uncertainty whether robot-assisted treatments are better than freehand approaches in terms of post-operative clinical outcomes. This metanalysis was conducted to compare the short-term clinical outcome between the robotic surgery and free hand screw placement technique.
Methods: Systematic review was conducted with the Preferred Reporting Items of Systematic Reviews (PRISMA) guidelines with studies i from 2018 until 2023. All studies that compared the robotic surgery and freehand pedicle screw placement in spinal surgery will be included. Outcome parameters analyzed were Oswestry disability index (ODI), visual analog scale (VAS) score, duration of surgery, and intraoperative blood loss. Heterogeneity was assessed using I^2 test, risk of bias was assessed using funnel plot, and analysis of comparison was done using the Review Manager Version 5.4.
Results: Eight studies involved in this study with total samples of 2,381. Quantitative analysis showed VAS with MD=0.20 95%IC=0.16-0.23 p<0.00001, ODI with MD=4.92 95%IC=4.72-5.12 p<0.00001, duration of surgery with MD=1.73 95%IC=0.85-2.61 p=0.00001, intraoperative blood loss with MD=-8.83 95%IC=(-11.56)-(-6.10) p<0.00001). From the four parameters, it showed statistically significant differences but considerable heterogeneity.
Conclusion: Robotic surgery gave better result in terms of VAS, ODI, duration of surgery, and intraoperative blood loss. However, this study still could not be applied extensively because of the considerable heterogeneity.

Keywords: robotic spine surgery, pedicle screw placement, minimally invasive surgery

INTRODUCTION

Pedicle screw placement is crucial in spine surgery because it provides stabilization in the reconstruction and controlled the fixed 3-column control. The traditional freehand technique is currently utilized as the primary way of placing pedicle screws. However, the operator's range of vision and posture are constrained by the available space in the traditional freehand screw insertion procedure. This might reduce screw

placement accuracy and result in pedicle violations. Incorrect placement of traditional freehand pedicle screws may result in dural rupture, nerve damage, and other issues. It varies from 3% to 55% in the thoracic spine and from 5 to 41% in the lumbar spine. Moreover, robot-assisted pedicle screw insertion has significantly evolved in recent years and several clinical cases have demonstrated its advantages over freehand screw placement such as increased precision and less intraoperative bleeding. The usage of artificial intelligence in robot-assisted machine had helped a lot in the spinal surgery.[1,2]

Nonetheless, uncertainty still persists on whether robot-assisted treatments are better than freehand approaches in terms of post-operative clinical outcomes. Although, several reviews and meta-analyses have specifically addressed this problem. This metanalysis was conducted in order to ascertain if the robot-assisted pedicle screw insertion approach delivers a benefit in short-term clinical results compared to the freehand screw placement technique.

MATERIALS & METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items of Systematic Reviews (PRISMA) guidelines.[3] Studies were identified through an electronic systematic search of PubMed, Embase (Elsevier), Cochrane Central (Wiley), Scopus (Elsevier), and ClinicalTrials.gov. The search keywords used were related to "robotic", "pedicle screw", "spinal surgery" using Boolean operator AND and OR. We limited the studies from 2018 until 2023 used in this study to ensure the source was updated and relevant with the current situation. Resulting studies were screened by the relevance of titles and abstracts. We excluded articles that published in non-peer- reviewed journals, lack of an abstract, and duplicates of already included papers. All studies that compared the robotic surgery and freehand pedicle screw placement in spinal surgery will be included.

Data that was extracted including authors' name, publication year, region, sample, and summary of outcomes. Qualitative data that reported 95% confidence interval (CI) and significant p value < 0.05 from the summary of outcomes will be analysed if there were more than equal to two articles that had the same measurements. Outcome parameters analysed were Oswestry disability index (ODI), visual analog scale (VAS) score, duration of surgery, and intraoperative blood loss. Heterogeneity was assessed using I^2 test, risk of bias was assessed using funnel plot, and analysis of comparison was done using the Review Manager Version 5.4.[4]

RESULT

There were eight studies involved in this study. Five studies were randomized controlled trial, while the other were retrospective studies. Two studies used Renaissance machine while the others used Tianji Robot (TiRobot). Results could be seen in Table 1.

Table 1. Tabulated study results

Study	Study Design	Country	Robot Type
Cui GY 2021[5]	Randomized Controlled Trial	China	TiRobot ®
Fan M 2020[6]	Randomized Controlled Trial	China	TiRobot ®
Feng S 2020[7]	Randomized Controlled Trial	China	TiRobot ®
Kim HJ 2018[8]	Randomized Controlled Trial	Korea	Renaissance ®
Lin S 2020[9]	Retrospective study	China	TiRobot ®
Tian Y 2020[10]	Retrospective study	China	Renaissance ®
Zhang QI 2019[11]	Randomized Controlled Trial	China	TiRobot ®
Zhang TT 2021[12]	Retrospective study	China	TiRobot ®

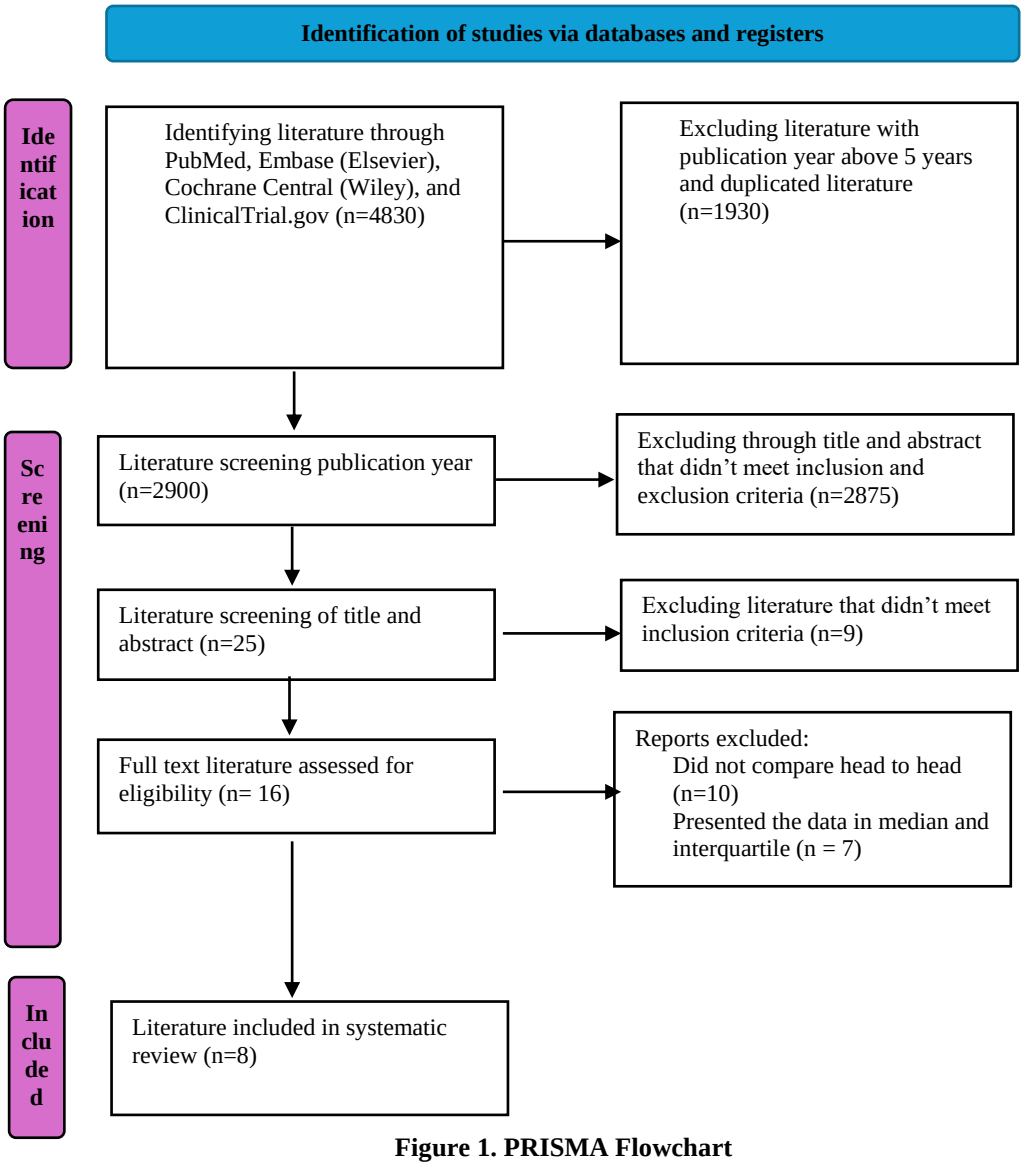
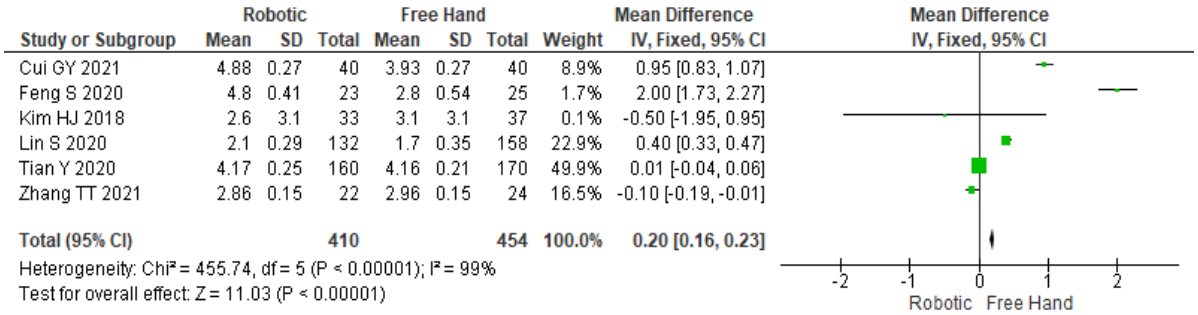


Figure 1. PRISMA Flowchart

Results

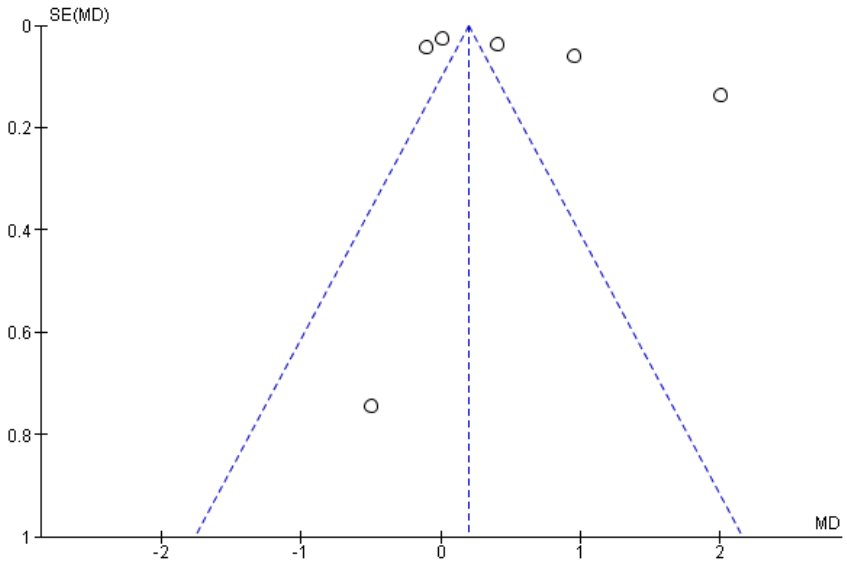
Visual Analog Scale (VAS)

Six studies with 410 samples from the robotic group and 454 from the free hand group were involved in the analysis of VAS. It was found that there was a significant difference (MD=0.20 95%IC=0.16-0.23 p<0.00001). Heterogeneity test showed considerable heterogeneity and statistically significant (I^2=99% p<0.00001). It was supported by the funnel plot that showed asymmetry distribution.



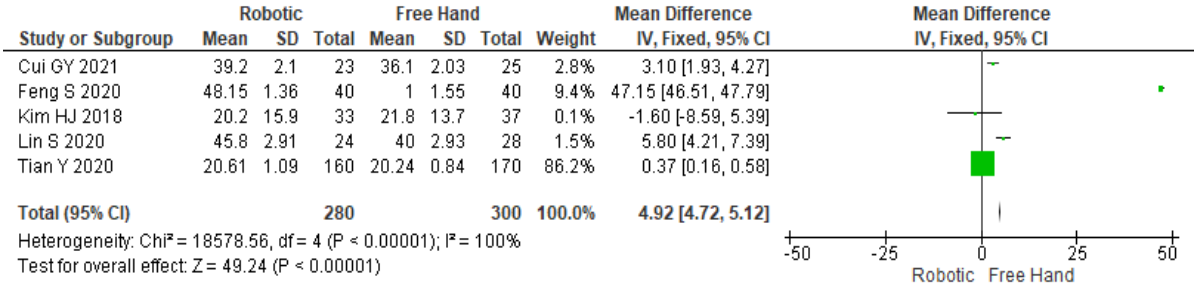
Study or Subgroup	Robotic Mean	Robotic SD	Robotic Total	Free Hand Mean	Free Hand SD	Free Hand Total	Weight	Mean Difference IV, Fixed, 95% CI
Cui GY 2021	4.88	0.27	40	3.93	0.27	40	8.9%	0.95 [0.83, 1.07]
Feng S 2020	4.8	0.41	23	2.8	0.54	25	1.7%	2.00 [1.73, 2.27]
Kim HJ 2018	2.6	3.1	33	3.1	3.1	37	0.1%	-0.50 [-1.95, 0.95]
Lin S 2020	2.1	0.29	132	1.7	0.35	158	22.9%	0.40 [0.33, 0.47]
Tian Y 2020	4.17	0.25	160	4.16	0.21	170	49.9%	0.01 [-0.04, 0.06]
Zhang TT 2021	2.86	0.15	22	2.96	0.15	24	16.5%	-0.10 [-0.19, -0.01]
Total (95% CI)			**410**			**454**	**100.0%**	**0.20 [0.16, 0.23]**

Heterogeneity: Chi² = 455.74, df = 5 (P < 0.00001); I² = 99%
Test for overall effect: Z = 11.03 (P < 0.00001)



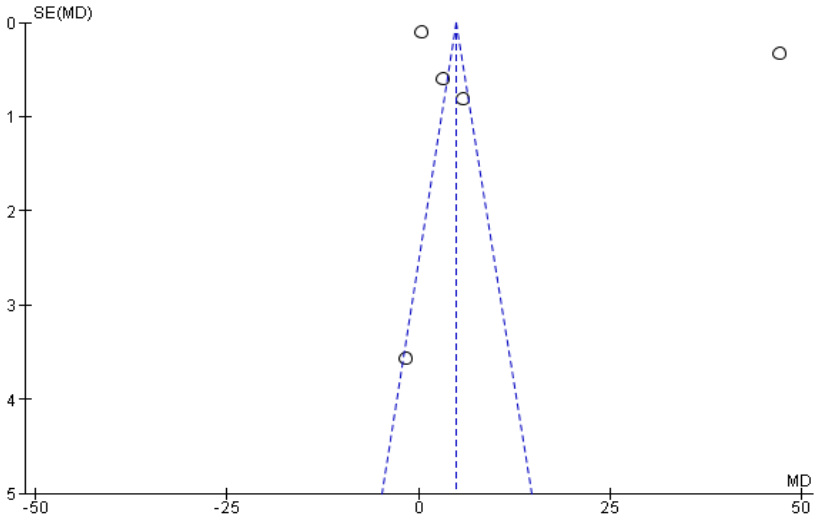
Oswestry Disability Index (ODI)

Five studies with 280 samples from the robotic group and 300 from the free hand group were involved in the analysis of ODI. It was found that there was a significant difference (MD=4.92 95%IC=4.72-5.12 p<0.00001). Heterogeneity test showed considerable heterogeneity and statistically significant (I^2=100% p<0.00001). It was supported by the funnel plot that showed asymmetry distribution.



Study or Subgroup	Robotic Mean	Robotic SD	Robotic Total	Free Hand Mean	Free Hand SD	Free Hand Total	Weight	Mean Difference IV, Fixed, 95% CI
Cui GY 2021	39.2	2.1	23	36.1	2.03	25	2.8%	3.10 [1.93, 4.27]
Feng S 2020	48.15	1.36	40	1	1.55	40	9.4%	47.15 [46.51, 47.79]
Kim HJ 2018	20.2	15.9	33	21.8	13.7	37	0.1%	-1.60 [-8.59, 5.39]
Lin S 2020	45.8	2.91	24	40	2.93	28	1.5%	5.80 [4.21, 7.39]
Tian Y 2020	20.61	1.09	160	20.24	0.84	170	86.2%	0.37 [0.16, 0.58]
Total (95% CI)			**280**			**300**	**100.0%**	**4.92 [4.72, 5.12]**

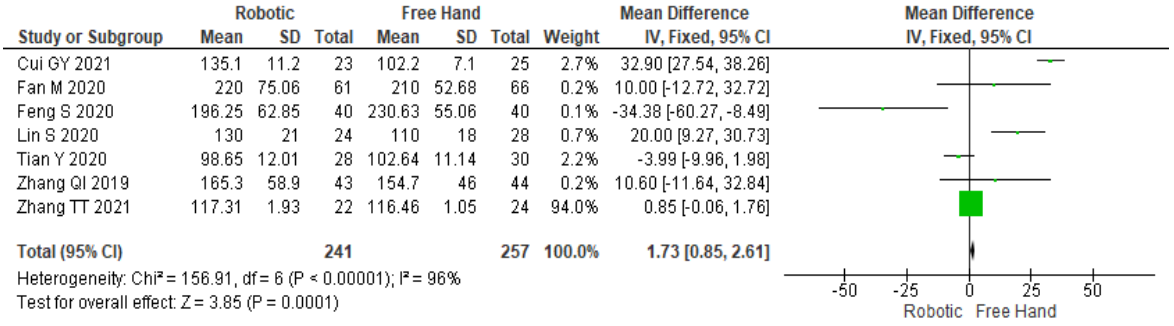
Heterogeneity: Chi² = 18578.56, df = 4 (P < 0.00001); I² = 100%
Test for overall effect: Z = 49.24 (P < 0.00001)



Duration of surgery

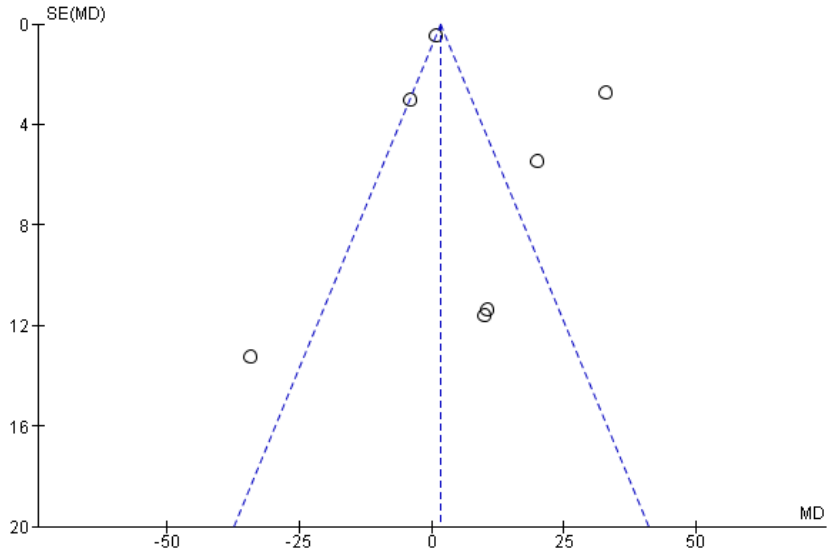
Seven studies with 241 samples from the robotic group and 257 from the free hand group were involved in the analysis of surgery duration. It was found that there was a significant difference (MD=1.73

95%IC=0.85-2.61 p=0.00001). Heterogeneity test showed considerable heterogeneity and statistically significant (I^2=96% p<0.00001). It was supported by the funnel plot that showed asymmetry distribution.



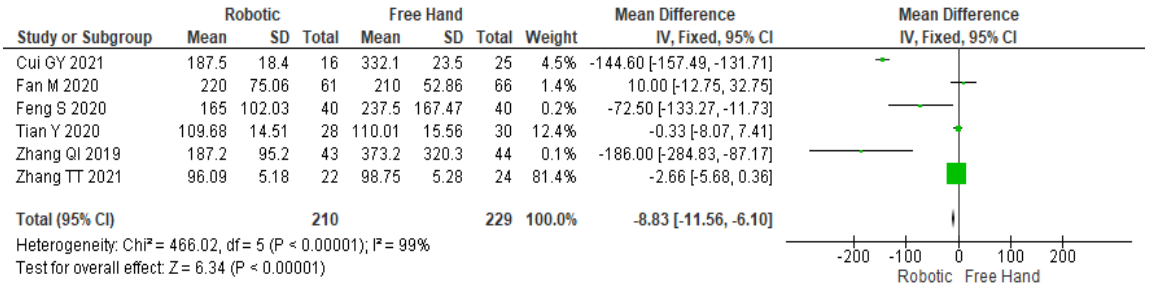
Study or Subgroup	Robotic Mean	SD	Total	Free Hand Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Cui GY 2021	135.1	11.2	23	102.2	7.1	25	2.7%	32.90 [27.54, 38.26]
Fan M 2020	220	75.06	61	210	52.68	66	0.2%	10.00 [-12.72, 32.72]
Feng S 2020	196.25	62.85	40	230.63	55.06	40	0.1%	-34.38 [-60.27, -8.49]
Lin S 2020	130	21	24	110	18	28	0.7%	20.00 [9.27, 30.73]
Tian Y 2020	98.65	12.01	28	102.64	11.14	30	2.2%	-3.99 [-9.96, 1.98]
Zhang QI 2019	165.3	58.9	43	154.7	46	44	0.2%	10.60 [-11.64, 32.84]
Zhang TT 2021	117.31	1.93	22	116.46	1.05	24	94.0%	0.85 [-0.06, 1.76]
Total (95% CI)			**241**			**257**	**100.0%**	**1.73 [0.85, 2.61]**

Heterogeneity: Chi² = 156.91, df = 6 (P < 0.00001); I² = 96%
Test for overall effect: Z = 3.85 (P = 0.0001)



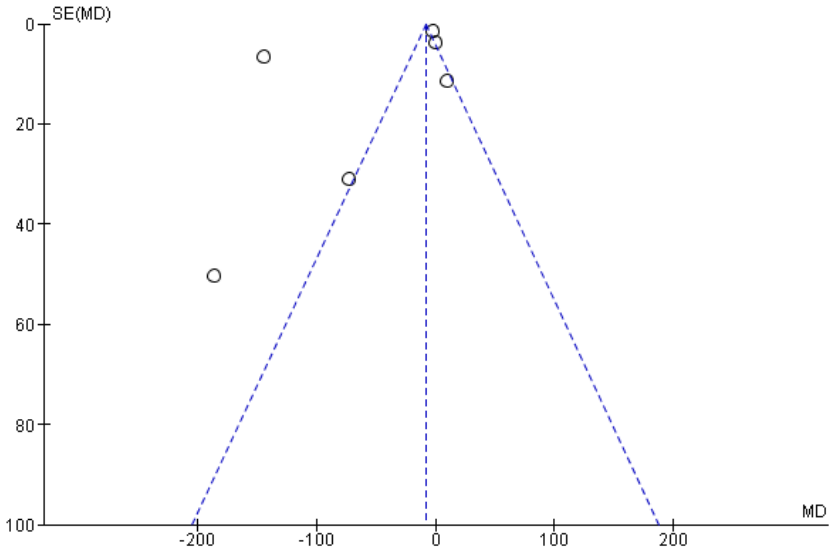
Intraoperative blood loss

Six studies with 210 samples from the robotic group and 229 from the free hand group were involved in the analysis of VAS. It was found that there was a significant difference (MD=-8.83 95%IC= (-11.56) -(-6.10) p<0.00001). Heterogeneity test showed considerable heterogeneity and statistically significant (I^2=99% p<0.00001). It was supported by the funnel plot that showed asymmetry distribution.



Study or Subgroup	Robotic Mean	SD	Total	Free Hand Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Cui GY 2021	187.5	18.4	16	332.1	23.5	25	4.5%	-144.60 [-157.49, -131.71]
Fan M 2020	220	75.06	61	210	52.86	66	1.4%	10.00 [-12.75, 32.75]
Feng S 2020	165	102.03	40	237.5	167.47	40	0.2%	-72.50 [-133.27, -11.73]
Tian Y 2020	109.68	14.51	28	110.01	15.56	30	12.4%	-0.33 [-8.07, 7.41]
Zhang QI 2019	187.2	95.2	43	373.2	320.3	44	0.1%	-186.00 [-284.83, -87.17]
Zhang TT 2021	96.09	5.18	22	98.75	5.28	24	81.4%	-2.66 [-5.68, 0.36]
Total (95% CI)			**210**			**229**	**100.0%**	**-8.83 [-11.56, -6.10]**

Heterogeneity: Chi² = 466.02, df = 5 (P < 0.00001); I² = 99%
Test for overall effect: Z = 6.34 (P < 0.00001)



DISCUSSION

During spinal surgery, a spine surgeon needs to have a steady hand and thorough skills. The complex surgical procedures could reduce the accuracy of the pedicle screw placement.[13] Robotic surgery was an approach where surgeon would be assisted with robot to place the pedicle screw. Therefore, this robot would not replace fully the operator. There was other several systems including Mazor X Stealth Edition Robotic Guidance System® by Medtronic, TiRobot® system TINAVI Medical Technologies Co. Ltd., ROSA® robot by Medtech, ExcelsiusGPS® robot by Globus Medical, and the SurgiBot® and ALF-X Surgical Robotic® systems from TransEnterix which depended on navigation-based systems that need an optical tracking device or relied on the preoperative plan. An artificial intelligence program aided the preoperative planning that ran on the workstation. While leaving the actual execution of the surgical process in the surgeon, robot-assisted systems guide the surgeon to the proper position and aid in improving precision.[14]

There were eight studies involved in this study with total samples of 2,381. From the four parameters, it showed differences which was statistically significant. The author inferred from this quantitative analysis that robotic surgery gave better result in terms of VAS, ODI, duration of surgery, and intraoperative blood loss.

This study was accordance with a meta-analysis by Li Y in 2023 that showed robotic gave better result in terms of VAS, intraoperative blood loss, and the length of hospitalization.[15] However, a study by Fu W in 2020 showed that robot-assisted techniques gave shorter postoperative stay, lower intraoperative blood loss. But in terms of surgical, VAS, and ODI scores, there were not significant differences.[16] Although both of these studies compared the same parameters, there were significant difference. Study by Li compared the difference of pre and post operative parameters, while study by Fu compared the post operative parameter head to head.

Injuries to vessels, neural structures, and the dura could happen from screw misplaced more than the tolerable distance (>2mm), particularly if the patient's anatomy has been changed.[13] If the neural structures was injured, a misplaced screw might affect the VAS and ODI score since both of them were related. Then, if the vessels were injured, then the volume intraoperative bleeding will be higher. Moreover, misplaced screws may also result in instability, fractures, weak biomechanical structure, and decreased fusion rates.[17] Although some studies have reported complication rates for pedicle screws ranging from 1% to 54%10,34-36, there is

insufficient data that differ real screw malposition rates from specific clinical problems.[14] According to Hu et al. in 2013, 960 screws were misaligned and ten of those were identified quickly and manually corrected intraoperatively. But in several occasion, an L3 radiculopathy developed in the misplaced screw patient which was not immediately noticed.[14]

However, the heterogeneity of this study was considerable. Hence, further evaluation was needed since this study was limited in samples and also there were two studies that used different robots. Operator experiences also played important factor here since the robot only assist with the preoperative plans.

CONCLUSION

Robotic surgery gave better result in terms of VAS, ODI, duration of surgery, and intraoperative blood loss. However, this study still could not be applied extensively because of the considerable heterogeneity.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

1. Mason A, Paulsen R, Babuska JM, Rajpal S, Burneikiene S, Nelson EL, Villavicencio AT. The accuracy of pedicle screw placement using intraoperative image guidance systems. J Neurosurg Spine. 2014;20(2):196–203. doi: 10.3171/2013.11.SPINE13413
2. Tan S, Teo E, Chua H. Quantitative three-dimensional anatomy of cervical, thoracic and lumbar vertebrae of Chinese Singaporeans. Eur Spine J. 2004; 13:137-146.
3. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. PLOS Medicine [Internet]. 2021 [cited 2022 Feb 22];18(3):e1003583 [15p.]. Available from: https://doi.org/10.1371/journal.pmed.1003583
4. Review Manager (RevMan) [Computer program]. Version 5.4. The Cochrane Collaboration. 2020
5. Cui GY, Han XG, Wei Y, Liu YJ, He D, Sun YQ, Liu B, Tian W. Robot-assisted minimally invasive transforaminal lumbar interbody fusion in the treatment of lumbar spondylolisthesis. Orthop Surg. 2021;13(7):1960–1968. doi: 10.1111/os.13044.
6. Fan M, Liu Y, He D, Han X, Zhao J, Duan F, Liu B, Tian W. Improved Accuracy of Cervical Spinal Surgery With Robot-Assisted Screw Insertion: A Prospective, Randomized, Controlled Study. Spine (Phila Pa 1976). 2020 Mar 1;45(5):285-291. doi: 10.1097/BRS.0000000000003258. PMID: 31568094.
7. Feng S, Tian W, Wei Y. Clinical effects of oblique lateral interbody fusion by conventional open versus percutaneous robot-assisted minimally invasive pedicle screw placement in elderly patients. Orthop Surg. 2020;12(1):86–93. doi: 10.1111/os.12587.
8. Kim H-J, Kang K-T, Chun H-J, et al. Comparative study of 1-year clinical and radiological outcomes using robot-assisted pedicle screw fixation and freehand technique in posterior lumbar interbody fusion: a prospective, randomized controlled trial. Int J Med Robot Comput Assist Surg. 2018;14:e1917.
9. Lin S, Hu J, Wan L, Tang L, Wang Y, Yu Y, Zhang W. Short-term effectiveness comparision between robotic-guided percutaneous minimally invasive pedicle screw internal fixation and traditional open internal fixation in treatment of thoracolumbar fractures. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu chongjian waike zazhi = Chinese journal of reparative and reconstructive surgery, 2020;34(1), 76–82. 10.7507/1002-1892.201906105.
10. Tian Y, Zhang J, Chen H, Ding K, Liu T, Huang D, Hao D. A comparative study of spinal robot-assisted and traditional fluoroscopy-assisted percutaneous reduction and internal fixation for single-level thoracolumbar fractures without neurological symptoms. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu

chongjian waike zazhi = Chinese Journal of Reparative and Reconstructive Surgery, 2020;34(1), 69–75. 10.7507/1002-1892.201905057.
11. Zhang QI, Xu Y-F, Tian W, et al. Comparison of Superior-level facet joint violations between robot-assisted percutaneous pedicle screw placement and conventional open fluoroscopic-guided pedicle screw placement. Orthop Surg. 2019; 11:850-856.
12. Zhang TT, Wang ZP, Wang ZH, Weng J, Chi F, Xue W, Song YX, Liu L. Clinical application of Orthopedic Tianji Robot in surgical treatment of thoracolumbar fractures. China J Orthopaedics Traumatol. 2021;34(11), 1034–9. 10.12200/j.issn.1003-0034.2021.11.010.
13. Gao S, Lv Z, Fang H. Robot-assisted and conventional freehand pedicle screw placement: a systematic review and meta-analysis of randomized controlled trials. Eur Spine J. 2018 Apr;27(4):921-930. doi: 10.1007/s00586-017-5333-y. Epub 2017 Oct 14. PMID: 29032475.
14. Lieberman IH, Kisinde S, Hesselbacher S. Robotic-Assisted Pedicle Screw Placement During Spine Surgery. JBJS Essent Surg Tech. 2020 May 21;10(2):e0020. doi: 10.2106/JBJS.ST.19.00020. PMID: 32944411; PMCID: PMC7478327.
15. Li Y, Wang Y, Ma X, Ma J, Dong B, Yang P, Sun Y, Zhou L, Shen J. Comparison of short-term clinical outcomes between robot-assisted and freehand pedicle screw placement in spine surgery: a meta-analysis and systematic review. J Orthop Surg Res. 2023 May 16;18(1):359. doi: 10.1186/s13018-023-03774-w. PMID: 37189203; PMCID: PMC10186789.
16. Fu W, Tong J, Liu G, Zheng Y, Wang S, Abdelrahim MEA, Gong S. Robot-assisted technique vs conventional freehand technique in spine surgery: a meta-analysis. Int J Clin Pract. 2021; 75(5):e13964. doi: 10.1111/ijcp.13964.
17. Macke JJ, Woo R, Varich L. Accuracy of robot-assisted pedicle screw placement for adolescent idiopathic scoliosis in the pediatric population. J Robot Surg. 2016; 10:145–150. https://doi. org/10.1007/s11701-016-0587-7 27.
18. Hu X, Ohnmeiss DD, Lieberman IH. Robotic-assisted pedicle screw placement: lessons learned from the first 102 patients. Eur Spine J. 2013. March; 22(3):661-6. Epub 2012 Sep 14.

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