

Review Article

Robotic Assistance in Pedicle Screw Placement for Adult Spinal Deformity

Perrin E^{1*}, Pichler L² and Todorova I³

¹Department of Spinal Surgery, University of Lyon, Lyon, France

²Department of Neurosurgery, University of Innsbruck, Innsbruck, Austria

³Department of Biomedical Engineering, Medical University of Sofia, Sofia, Bulgaria

***Address for Correspondence:** Elodie Perrin, Department of Spinal Surgery, University of Lyon, Lyon, France;
E-mail: elodie.perrin@universityoflyon.edu

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Abstract

Background: Adult spinal deformity surgery often needs long constructs placed through osteoporotic, rotated, or previously operated pedicles. Screw malposition here risks neurologic injury and construct failure.

Objective: To synthesize published evidence on robotic-assisted pedicle screw placement in adult spinal deformity.

Methods: Narrative review of comparative studies, systematic reviews, meta-analyses, and cost analyses of Mazor, ROSA, ExcelsiusGPS, and related platforms.

Findings: Robotic guidance achieves Gertzbein-Robbins Grade A/B accuracy above 97-99%. It modestly outperforms fluoroscopy-guided freehand technique and reduces radiation exposure. Setup time adds an early cost that shortens with experience over roughly twenty to thirty cases. Revision rates for malpositioned screws are low, and cost analyses suggest savings from avoided revisions can offset added expense.

Conclusions: Robotic assistance offers a reproducible accuracy advantage relevant to long-construct deformity correction. Evidence still comes mainly from single-center series rather than deformity-specific randomized trials.

Keywords: Robotic surgery; Pedicle screw; Adult spinal deformity; Spine navigation; Surgical accuracy

Abstract

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Introduction

Adult spinal deformity (ASD) surgery is among the most technically demanding domains of spine surgery. Long, multi-level constructs must be anchored through pedicles that are frequently narrowed, rotated, osteoporotic, or distorted by prior instrumentation, and a single malpositioned screw can produce neurologic injury, vascular injury, or early construct failure requiring revision. The Gertzbein-Robbins classification, originally developed to grade pedicle wall breach on postoperative imaging, remains the standard metric by which screw accuracy is judged across the literature, with Grade A (no breach) and Grade B (breach under 2 mm) generally

treated as clinically acceptable [1].

Robotic guidance systems were introduced to reduce the variability of freehand and fluoroscopy-guided screw placement by coupling preoperative or intraoperative imaging with a mechanical arm or platform that constrains the trajectory of instrumentation. The lineage runs from the early SpineAssist system through Mazor X and Mazor X Stealth Edition, to the ROSA Spine robot, ExcelsiusGPS, and newer platforms such as CUVIS-spine, each iteration adding features such as intraoperative CT registration, real-time tracking, or combined navigation-robotic workflows [2]. Adoption in ASD has followed more slowly than in degenerative lumbar surgery, given the added complexity of long registration chains spanning multiple vertebral levels and the deformed anatomy itself, but a growing literature now addresses robotic guidance specifically in deformity cohorts [3,4].

Accuracy is not simply a technical curiosity in deformity surgery: a misplaced screw in a long thoracolumbar construct can necessitate an unplanned return to the operating room in a patient who has already undergone extensive osteotomies, blood loss, and anesthetic time, so any technology that lowers this risk carries outsized clinical weight relative to shorter, simpler fusions. At the same time, deformity correction adds registration and workflow complexity that shorter-segment robotic series do not fully capture, so evidence generated in degenerative lumbar cohorts must be extrapolated to deformity practice with some caution.

This review synthesizes published comparative studies, systematic reviews, meta-analyses, and economic analyses addressing robotic-assisted pedicle screw placement, with particular attention to accuracy, comparison with fluoroscopy- and navigation-guided freehand technique, radiation exposure, operative time

and learning curve, complications and revision, cost-effectiveness, and considerations specific to long-construct deformity correction.

Robotic Platforms and Screw Accuracy

Platform-specific series report consistently high accuracy. An ExcelsiusGPS series found 98.8% of 517 screws graded A or B, with a 0% 90-day revision rate, though early complications, mostly surgical site infection, occurred in 7.2% of cases [5]. A larger 728-screw ExcelsiusGPS analysis, and a dedicated study of deviation from the pre-planned trajectory with the same platform, similarly documented accuracy in the high-90% range with millimeter-scale deviations from plan [6,7]. Comparable results have been reported for Mazor-X against a newer Fusion Robotics platform in single-level lumbar placement [8], for the ROSA Spine robot coupled with intraoperative flat-panel CT in a cadaveric model of thoracolumbar and vertebral body screw placement [9], and for a newer entrant, CUVIS-spine, in a multicenter series reporting 97.99% Grade A/B accuracy with automated three-dimensional offset measurement and zero neurovascular complications [10]. An independent multicenter analysis using a computer-vision algorithm to automatically quantify deviation across 500 robotically placed screws reinforced that measured accuracy is high and largely consistent across sites when assessed with standardized, automated methods rather than subjective visual grading [11]. Beyond the lumbar spine, case reports document Mazor X-guided placement extending to upper and lower cervical pedicle screws, illustrating the platforms' versatility across regions that a long deformity construct may traverse [12]. Taken together, these platform-specific series share a common pattern: accuracy figures cluster tightly in the high-90% range regardless of the particular robot used, while the residual difference between platforms appears to depend more on registration workflow, imaging modality, and surgeon

experience than on any single mechanical design.

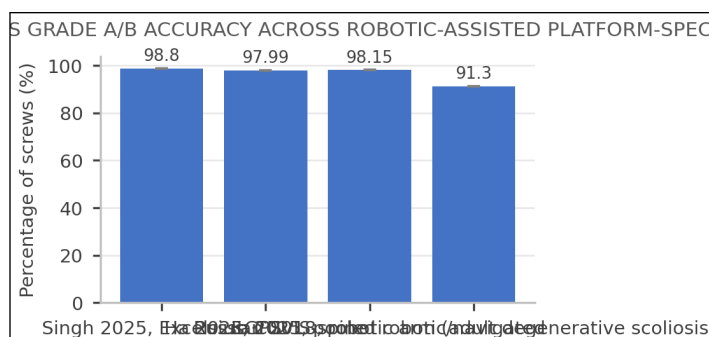


Figure 1: Gertzbein-Robbins Grade A/B pedicle screw accuracy reported across robotic-assisted platform-specific series [5,10,16,14].

Comparison with Fluoroscopy- and Navigation-Guided Freehand Technique

Meta-analytic evidence generally favors robotic guidance over fluoroscopy-guided freehand placement, though the margin is modest. A systematic review and meta-analysis of 21 studies found robotic-assisted screws roughly 1.02 times more likely to achieve Grade A or B accuracy than fluoroscopy-guided screws, with the advantage more pronounced when restricted to Grade A alone; fluoroscopy-guided surgery retained shorter operating times, while robotic guidance reduced radiation dose, and blood loss did not differ meaningfully between techniques [13]. A three-arm comparison in adult degenerative scoliosis found robotic guidance achieved 91.3% "perfect" accuracy versus 81.3% with a drill-guide template and 84.1% with CT-based navigation, again with reduced radiation exposure but no shortening of operative time [14]. In scoliosis populations more broadly, a meta-analysis comparing robot-assisted, navigation-based, and freehand posterior fusion techniques found robotic assistance associated with the highest screw accuracy of the three approaches [15], and a systematic review pooling 15 studies, 1,487 patients, and 7,274 screws across navigated and robotic platforms found 98.15% of screws graded A or B, underscoring that both modern navigation and robotics now substantially

outperform historical freehand benchmarks [16]. A direct comparison of robotic-assisted against navigation-guided lumbar fusion additionally found differences in complication rates, cost, mortality, and length of stay between the two image-guided strategies themselves, indicating that not all technology-assisted approaches are interchangeable [17]. These findings collectively argue against treating "image guidance" as a single category: freehand fluoroscopy, standalone navigation, and robotic guidance each carry a distinct accuracy, time, and radiation profile, and deformity surgeons choosing among them are choosing among three meaningfully different risk-benefit trade-offs rather than variations on one technique.

Table 1: Comparative studies of robotic-assisted versus fluoroscopy-guided and navigation-guided freehand pedicle screw placement [13,14,15,16,17].			
Study	Comparison	Metric	Result
Verma 2024	Robotic vs fluoroscopy-guided	Grade A/B likelihood	~1.02x more likely with robotic
Fan 2018	Robot vs drill guide vs CT navigation	"Perfect" accuracy	91.3% vs 81.3% vs 84.1%
Al-Naseem 2024	Robot vs navigation vs freehand (scoliosis)	Screw accuracy	Highest with robotic assistance
Russo 2025	Pooled navigated and robotic platforms	Grade A/B, 7,274 screws	98.15% Grade A/B
Maman 2025	Robotic-assisted vs navigation-guided	Complications, cost, mortality, LOS	Differences favor neither uniformly

Radiation Exposure

Reduction in intraoperative radiation is among the most consistent findings across the robotic literature, reflecting reliance on preoperative or intraoperative three-dimensional imaging rather than repeated live fluoroscopic shots during screw insertion. A systematic review, meta-analysis, and meta-regression of 3,205 patients found robotic-assisted surgery associated with materially lower radiation exposure than conventional

fluoroscopy-guided and, in most comparisons, navigation-assisted technique [18], a pattern echoed in the deformity-focused three-technology comparison above [14] and in the accuracy meta-analysis contrasting robotic and fluoroscopic approaches [13]. For surgeons and operating-room staff exposed repeatedly over a career, and for patients undergoing the long fluoroscopic exposures that multi-level deformity constructs can otherwise require, this reduction is a clinically meaningful advantage independent of screw accuracy itself. Cumulative occupational dose is a particular concern for spine surgeons who instrument many levels per case across a high case volume, and several of the same studies reporting accuracy gains also report that robotic guidance shifts imaging away from live fluoroscopy toward preoperative or intraoperative cross-sectional acquisitions, concentrating radiation exposure into fewer, more controlled episodes rather than distributing it across the length of the procedure.

Operative Time and Learning Curve

Robotic guidance imposes an initial time cost, primarily from platform setup, registration, and troubleshooting, that diminishes as surgeons and teams gain experience. A systematic review of learning curves across robotic platforms found that most published curves stabilize within roughly twenty to forty cases, and proposed formal incorporation of robotic training into residency curricula given this defined trajectory [19]. Focused single-center analyses support this range: cumulative sum analysis of the first 50 cases at one center found the learning phase completed after 23 cases, with screw-insertion time falling significantly thereafter, though total operative time did not correspondingly shorten [20], and a companion analysis decomposing operative time into screw insertion, robot setting, registration, and fluoroscopy confirmed that setup-related components, rather than screw placement itself, account for most of the early time penalty and most

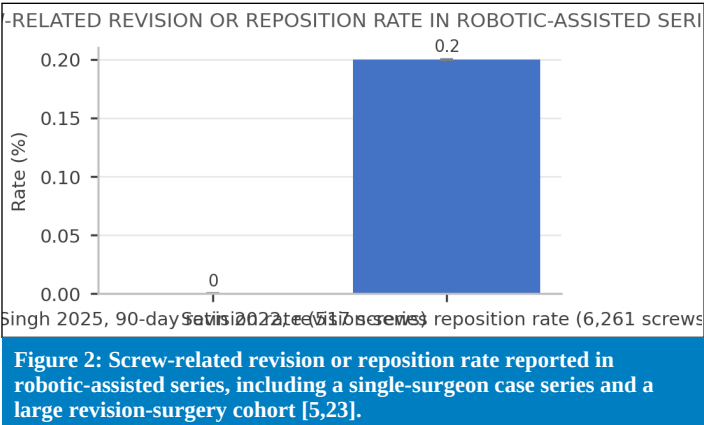
of the subsequent improvement [21]. A K-wire-free robotic and navigation-assisted technique in adult degenerative spinal surgery likewise demonstrated a defined learning curve with technical refinements that shortened procedure time across the reported case series [22]. A broader narrative review situates these learning-curve data alongside platform accuracy and economic findings, noting that the time penalty is front-loaded and is not, in most series, an argument against adoption once a program reaches maturity [4]. The consistency of a twenty-to-forty-case plateau across platforms and institutions suggests that the learning curve reflects team-level workflow familiarity — operating-room staff, radiology technologists, and the surgeon together — rather than surgeon skill in isolation, which has implications for how training programs and hospital credentialing committees structure early case supervision.

Table 2: Reported learning-curve findings for robotic-assisted pedicle screw placement [19,20,21,22].			
Study	Platform	Cases	Learning-curve finding
Pennington 2022	Multiple platforms (review)	21 studies pooled	Curve stabilizes over ~20-40 cases
Torii 2022	Mazor X Stealth Edition	50	Plateau after 23 cases (CUSUM)
Akazawa 2024	Mazor X Stealth Edition	50	Setup/registration time drives improvement
Avrumova 2021	K-wireless robotic/navigation	Case series	Defined curve, shortened procedure time

Complications, Revision Rates, and Cost-Effectiveness

Screw-related revision rates with robotic guidance are consistently low. In a series of 628 robotic-assisted revision spine procedures spanning six years, only 0.2% of 6,261 implanted screws required repositioning, despite the distorted anatomy characteristic of revision and, by extension, prior deformity surgery [23]. Economic analyses generally find that avoided revisions, shorter hospital stays, and fewer infections can offset the added

capital and per-case cost of robotic platforms. A single-center analysis across 557 thoracolumbar instrumentation cases estimated approximately \$608,546 in first-year conservative cost savings after integrating robotic technology [24], and an independent single-center retrospective cost-effectiveness analysis reached similar directional conclusions [25]. A matched-cohort comparison of index surgery cost between fluoroscopic freehand and robotic-assisted lumbar screw placement found the two approaches converge once matched for age, sex, and surgical approach, suggesting the economic case for robotics rests more on downstream revision avoidance than on the index procedure alone [26]. Together these analyses imply that the capital cost of a robotic platform is best evaluated against a hospital's revision burden and case volume rather than against the incremental cost of a single index procedure, a distinction that matters most in high-volume deformity centers where even a small absolute reduction in revision surgery affects many patients over the life of the equipment.



Long-Construct Deformity-Specific Considerations

The evidence reviewed above derives disproportionately from degenerative and short-segment lumbar cohorts, and deformity-specific data remain comparatively limited. The systematic review focused specifically on ASD found that accuracy, alignment, and complication

outcomes with robotic platforms in deformity cohorts broadly parallel those in non-deformity populations, but flagged registration across long, rotated constructs and the added time of instrumenting many levels as unresolved practical challenges rather than settled advantages [3]. Given the low absolute revision rates achievable even in complex revision anatomy [23] and the radiation savings that accrue disproportionately over long multi-level exposures [18], robotic guidance appears well suited in principle to long-construct deformity correction; confirming this benefit will require deformity-specific comparative studies rather than extrapolation from shorter-segment series.

Conclusion

Across platforms and study designs, robotic-assisted pedicle screw placement achieves high Gertzbein-Robbins Grade A/B accuracy, modestly exceeds fluoroscopy-guided freehand technique, and reduces radiation exposure, at the cost of a learning curve that stabilizes within several dozen cases. Revision rates are low even in technically demanding revision and, by inference, deformity anatomy, and cost-effectiveness analyses suggest that avoided complications can offset added expense. The evidence base, however, remains dominated by single-center series and mixed-pathology cohorts rather than adult-spinal-deformity-specific comparative trials, leaving the magnitude of benefit in long, multi-level deformity constructs still to be firmly established.

References

1. Gertzbein, S.D., Robbins, S.E. (1990) Accuracy of Pedicular Screw Placement In Vivo. *Spine*, 15(1): 11-14.
2. D'Souza, M., Gendreau, J., Feng, A., Kim, L.H., Ho, A.L., Veeravagu, A. (2019) Robotic-Assisted Spine Surgery: History, Efficacy, Cost, And Future Trends. *Robotic Surgery: Research and Reviews*, 6: 9-23.
3. Khalifeh, K., Brown, N.J., Pennington, Z., Pham, M.H. (2024) Spinal Robotics in Adult Spinal Deformity Surgery: A Systematic Review. *Neurospine*, 21(1): 20-29.
4. Antonacci, C.L., Zeng, F., Block, A., Davey, A., Makanji, H. (2024) Robotic-Assisted Spine Surgery: A Narrative Review. *Journal of Spine Surgery*, 10(2): 305-312.
5. Singh, E., Cardinal, T., Stillman, K., Jackson, S., Cable, C., Di, L., Tigchelaar, S., Khalafallah, A., Urakov, T. (2025) Clinical Outcomes and Complications of Robotic-Assisted Spine Surgery Using the ExcelsiusGPS System: A Single-Surgeon Case Series. *Journal of Robotic Surgery*, 19: 750.
6. Bhimreddy, M., Hersh, A.M., Jiang, K., Weber-Levine, C., Davidar, A.D., Menta, A.K., Judy, B.F., Lubelski, D., Bydon, A., Weingart, J., Theodore, N. (2024) Accuracy of Pedicle Screw Placement Using the ExcelsiusGPS Robotic Navigation Platform: An Analysis of 728 Screws. *International Journal of Spine Surgery*, 18(6): 712-720.
7. Jiang, B., Karim Ahmed, A., Zygorakis, C.C., Kalb, S., Zhu, A.M., Godzik, J., Molina, C.A., Blitz, A.M., Bydon, A., Crawford, N., Theodore, N. (2018) Pedicle Screw Accuracy Assessment in ExcelsiusGPS Robotic Spine Surgery: Evaluation of Deviation from Pre-Planned Trajectory. *Chinese Neurosurgical Journal*, 4: 23.
8. Soliman, M.A., Khan, A., O'Connor, T.E., Foley, K., Pollina, J. (2021) Accuracy and Efficiency of Fusion Robotics Versus Mazor-X in Single-Level Lumbar Pedicle Screw Placement. *Cureus*, 13(6): e15939.
9. Lefranc, M., Peltier, J. (2015) Accuracy of Thoracolumbar Transpedicular and Vertebral Body Percutaneous Screw Placement: Coupling the ROSA Spine Robot with Intraoperative Flat-Panel CT Guidance-A Cadaver Study. *Journal of Robotic Surgery*, 9(4): 331-338.
10. Ha, B.J., Lee, J.M., Yoon, S.J., Kim, B.K., Lee, J., Lee, S., Ryu, S., Cha, Y., Hwang, S., Woo, D., Lee, C.K., Shin, D.A., Ha, Y., Kuh, S.U., Kim, K.N., Son, D., Yi, S. (2023) Three-Dimensional

- Quantitative Assessment of Pedicle Screw Accuracy in Clinical Utilization of a New Robotic System in Spine Surgery: A Multicenter Study. *Neurospine*, 20(3): 1028-1039.
11. Volk, V.L., Steele, K.A., Cinello-Smith, M., Chua, R.V., Pollina, J., Poulter, G., Shafa, E., Busselberg, P., Fitzpatrick, C.K. (2023) Pedicle Screw Placement Accuracy in Robot-Assisted Spinal Fusion in a Multicenter Study. *Annals of Biomedical Engineering*, 51(11): 2518-2527.
 12. Gao, Z., Zhang, X., Xu, Z., Jiang, C., Hu, W., Zhang, H., Hao, D. (2024) Mazor X Robot-Assisted Upper and Lower Cervical Pedicle Screw Fixation: A Case Report and Literature Review. *BMC Geriatrics*, 24: 916.
 13. Verma, R. (2024) Robotic-Assisted Versus Fluoroscopic-Guided Surgery on the Accuracy of Spine Pedicle Screw Placement: A Systematic Review and Meta-Analysis. *Cureus*, 16(2): e54969.
 14. Fan, Y., Du, J.P., Liu, J.J., Zhang, J.N., Liu, S.C., Hao, D.J. (2018) Radiological and Clinical Differences Among Three Assisted Technologies in Pedicle Screw Fixation of Adult Degenerative Scoliosis. *Scientific Reports*, 8: 890.
 15. Al-Naseem, A.O., Al-Muhannadi, A., Ramadhan, M., Alfadhli, A., Marwan, Y., Shafafy, R., Abd-El-Barr, M.M. (2024) Robot-Assisted Pedicle Screw Insertion Versus Navigation-Based and Freehand Techniques for Posterior Spinal Fusion in Scoliosis: A Systematic Review and Meta-Analysis. *Spine Deformity*, 12(5): 1203-1215.
 16. Russo, F., Nardi, N., Papalia, G.F., Papalia, R., Vadalà, G., Denaro, V. (2025) Deviation from Preoperative Planning and Pedicle Screw Accuracy in Navigated and Robotic Spinal Fusion: A Systematic Review. *European Spine Journal*, 34(5): 1890-1899.
 17. Maman, D., Elhija, A.A., Mahamid, A., Laver, L., Behrbalk, E. (2025) Comparative Analysis of Complications, Costs, Mortality, and Length of Stay in Lumbar Fusion Surgery: Robotic-Assisted Versus Navigation-Guided Approaches. *European Spine Journal*, 34(9): 4132-4139.
 18. Rodríguez-Domínguez, V., Vivancos Sánchez, C., Taravilla-Loma, M., Gandía-González, M.L., Isla Guerrero, A. (2026) Radiation Exposure in Robotic-Assisted Versus Conventional and Navigation-Assisted Spine Surgery: A Systematic Review, Meta-Analysis, and Meta-Regression of 3205 Patients. *Journal of Clinical Medicine*, 15(6): 2144.
 19. Pennington, Z., Lakomkin, N., Judy, B.F., Zakaria, H.O., Mikula, A.L., Theodore, N. (2022) Learning Curves in Robot-Assisted Spine Surgery: A Systematic Review and Proposal of Application to Residency Curricula. *Neurosurgical Focus*, 52(1): E3.
 20. Torii, Y., Ueno, J., Iinuma, M., Yoshida, A., Niki, H., Akazawa, T. (2022) The Learning Curve of Robotic-Assisted Pedicle Screw Placements Using the Cumulative Sum Analysis: A Study of the First 50 Cases at a Single Center. *Spine Surgery and Related Research*, 6(6): 589-595.
 21. Akazawa, T., Torii, Y., Ueno, J., Umehara, T., Iinuma, M., Yoshida, A., Tomochika, K., Ohtori, S., Niki, H. (2024) Learning Curves for Robotic-Assisted Spine Surgery: An Analysis of the Time Taken for Screw Insertion, Robot Setting, Registration, and Fluoroscopy. *European Journal of Orthopaedic Surgery & Traumatology*, 34(1): 127-134.
 22. Avrumova, F., Morse, K.W., Heath, M., Widmann, R.F., Lebl, D.R. (2021) Evaluation of K-Wireless Robotic and Navigation Assisted Pedicle Screw Placement in Adult Degenerative Spinal Surgery: Learning Curve and Technical Notes. *Journal of Spine Surgery*, 7(2): 141-154.
 23. Satin, A.M., Kisinde, S., Lieberman, I.H. (2022) Robotic-Assisted Revision Spine Surgery. *International Journal of Spine Surgery*, 16(S2): S14-S21.
 24. Menger, R.P., Savardekar, A.R., Farokhi, F., Sin, A. (2018) A Cost-Effectiveness Analysis of the Integration of Robotic Spine Technology in Spine Surgery. *Neurospine*, 15(3): 216-224.

25. Chumnanvej, S., Ariyaprakai, K., Pillai, B.M., Suthakorn, J., Gurusamy, S., Chumnanvej, S. (2023) Cost-Effectiveness of Robotic-Assisted Spinal Surgery: A Single-Center Retrospective Study. *Laparoscopic, Endoscopic and Robotic Surgery*, 6(4): 147-153.
26. Ezeokoli, E.U., Pfennig, M., John, J., Gupta, R., Khalil, J.G., Park, D.K. (2022) Index Surgery Cost of Fluoroscopic Freehand Versus Robotic-Assisted Pedicle Screw Placement in Lumbar Instrumentation: An Age, Sex, and Approach-Matched Cohort Comparison. *JAAOS Global Research & Reviews*, 6(12): e22.00137.