Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Fixation of the thoracolumbar spine with augmented reality-supported rod bending in multilevel pedicle screw instrumentation: First results of a prospective pilot study

Bernardo Reyes Medina

bernardo.reyesmedina@klinikum-bayreuth.de

Bayreuth Medical Center

Christoph Sippl

Bayreuth Medical Center

Fatemeh Khafaji

Bayreuth Medical Center

Shafie Ariai

Bayreuth Medical Center

Saffwan Saffour

Bayreuth Medical Center

Stefan Linsler

Bayreuth Medical Center

Research Article

Keywords: Augmented reality, pedicle screw fixation, thoracolumbar spine, spinal instrumentation, rod contouring, screw loosening, screw pullout, ADVISE System

Posted Date: June 30th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9954428/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Pedicle screw fixation is the standard technique for thoracolumbar spinal stabilization. However, implant-related complications, including screw loosening and screw pullout, remain common, particularly in multilevel constructs and elderly patients. Rod–screw mismatch during rod insertion may generate substantial mechanical stress at the bone–implant interface and contribute to implant failure. Augmented reality (AR)-assisted rod contouring has been developed to facilitate accurate rod alignment and reduce the need for forceful rod reduction maneuvers. The aim of this study was to evaluate the feasibility, safety, and preliminary clinical outcomes of AR-assisted rod contouring using the ADVISE system in multilevel thoracolumbar instrumentation.

Methods

This prospective single-centre pilot study included 20 consecutive patients undergoing multilevel posterior thoracolumbar instrumentation with pedicle screw fixation assisted by AR-based rod contouring software (ADVISE, Neo Medical, Switzerland) between August 2024 and February 2026. Patients requiring instrumentation of at least three contiguous thoracolumbar segments for degenerative spinal pathology were eligible. Clinical and radiographic outcomes were assessed preoperatively and at three months postoperatively. Outcome measures included implant-related complications, screw pullout, hardware failure, Visual Analogue Scale (VAS) pain scores, and Oswestry Disability Index (ODI).

Results

Twenty patients (mean age 71.6 ± 6.7 years) underwent instrumentation across a mean of 4.15 ± 0.96 spinal levels. A total of 206 pedicle screws and 40 rods were implanted. All procedures were successfully completed using the AR-assisted workflow. No intraoperative screw pullout, implant-related technical failures, screw loosening, or rod fractures were observed during the follow-up period. Mean VAS scores improved significantly from 8.0 ± 0.9 preoperatively to 4.0 ± 0.8 at three months ($p < 0.001$). ODI improved from 69.2 ± 8.5 preoperatively to 45.6 ± 9.6 at three months ($p < 0.001$). Rod insertion was achieved without extensive reduction manoeuvres in all cases.

Conclusions

AR-assisted rod contouring using the ADVISE system appears feasible and safe for multilevel thoracolumbar instrumentation. The technology may facilitate improved rod–screw alignment and

reduce the need for forceful rod reduction. Larger comparative studies with longer follow-up are required to determine its impact on implant-related complications and long-term clinical outcomes.

Introduction

The first spinal stabilization systems were introduced in the 1950s by Paul Harrington, who used hooks and rods for the correction of scoliosis (1). The Harrington rod and instrumentation would become the standard of care for the management of scoliosis until the early 1980s (2). Roy-Camille promoted the use of pedicle screws as a point of fixation for thoracolumbar segmental fixation (3). The earlier version of pedicle screw was monoaxial and coupled with plates; later, it has evolved to the current rod-based system coupled with polyaxial screws (4). The pedicle screw fixation system has been accepted as the gold standard technique for spinal fusion (5). The primary goal of pedicle screw fixation of the spine is to stabilize the spine until solid fusion has occurred (6, 7).

Despite increasing surgical experience and advances in biomechanical research, spinal stabilization procedures are still associated with high complication rates, often requiring revision surgery (8, 9). The most common reasons for revision include adjacent segment degeneration, infections, pseudarthrosis, and other factors (9, 10). However, the most frequent cause of poor outcomes and revision surgery is hardware failure, with screw loosening and “screw pullout” being the primary causes (11–14).

Several studies have demonstrated pedicle screw loosening rates of up to 27% in patients with good bone quality and over 50% in patients with osteoporosis (15–19). A critical surgical step that significantly contributes to overload is forced rod fixation. It is estimated that more than 80% of screws are already loosened during this process due to misalignment between screw heads and rods (20). Correction of this misalignment during rod reduction can generate sufficient tension to cause screw pullout (21–23). Only if the rod fits exactly to the pedicle screws at a 90° angle without external intervention can a stress-reduced fixation be achieved (24).

Pedicle screw and rod interfacing angle mismatch is a frequent occurrence after spinal fixation surgery. Mismatches indicate that the construct was assembled under mechanical stress. Screw pullout during rod reduction, screw loosening, screw or rod breakage, adjacent segment degeneration and consequently more pain are associated with forced fixation. (6, 13, 25, 26). A computer assisted rod bending system showed a lower a pullout and screw loosening rate than with the traditional manual rod bending technique in pedicle screw fixation (22).

The use of augmented reality in the rod bending step has already been described, allowing controlled fixation in the thoracolumbar spine (27). However, there are no studies with short- or long-term results of this technique in multilevel spine fixation.

The present study aims henceforth to provide the first clinical evidence and results on AR-assisted rod alignment allowing controlled multilevel fixation.

Aim of the Study

The primary aim of this study was to evaluate the feasibility and safety of augmented reality–assisted rod contouring during multilevel thoracolumbar pedicle screw instrumentation.

The secondary aim was to assess early clinical and radiographic outcomes, including implant-related complications, postoperative pain, and functional recovery.

Hypothesis

We hypothesized that the use of augmented reality–based supported rod bending software may facilitate improved rod alignment and reduce the need for intraoperative rod reduction forces, potentially decreasing the risk of pedicle screw pullout, screw loosening, implant-related mechanical stress, and consequently reduce postoperative pain.

Methods

Study design and patient population

This prospective study included patients undergoing multilevel-segment posterior thoracolumbar fixation using pedicle screw instrumentation in patients with degenerative spine pathologies with the assistance of an augmented reality–based rod bending visualization software ADVISE (Neo Medical, Switzerland). Between August 2024 and February 2026, a total of 20 consecutive patients were enrolled at our Department of Neurosurgery, Medical Campus Upper Franconia, Hospital Bayreuth in Germany.

The study was conducted at the Department of Neurosurgery, Bayreuth Hospital, Medical Campus Upper Franconia, Friedrich-Alexander University Erlangen–Nuremberg, Germany. Ethical approval was obtained from the institutional ethics committee (Reference No. 25 – 20 Bm), and the study was registered in the German Clinical Trials Register (DRKS00039841). All procedures were performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrolment.

Patient Population

Patients were eligible for inclusion if they were older than 18 years and required posterior thoracolumbar instrumentation involving at least three contiguous spinal segments for degenerative spinal disease. All procedures were performed using the ADVISE augmented reality rod contouring system.

Exclusion criteria included previous instrumentation at the index level, active spinal infection, tumour-related spinal disease, and severe osteoporosis considered likely to compromise implant fixation.

All procedures were performed by two experienced spine surgeons using a standardized surgical workflow.

Augmented reality–assisted rod bending ADVISE software

For this study we used the Neo Medical (Villete, Switzerland) pedicle screw system, already described by Abdalla (28). The technical note of the use of the ADVISE software (Neo Medical, Switzerland) has been already described by Antes (27) as it follows: “The polyaxial screw heads of the Neo System are attached to removable guides that can be recognized by the ADVISE software during three-dimensional (3D) scanning. After all pedicle screws have been inserted, the ADVISE application is launched on an Apple iPad. To maintain sterility and prevent contamination of the operative field, the iPad is enclosed in a transparent sterile cover. Prior to scanning, the surgeon designates the patient’s head orientation according to whether the scan will begin from the left or right side. The iPad camera is then moved around the surgical field to perform scene analysis and calibrate the light detection and ranging scanner before initiating the 3D scan. Using the predefined dimensions and geometry of the guides, the software detects their position within the camera image. Successful identification is displayed by superimposing virtual guide models onto the corresponding physical guides (Fig. 1). Color-coded visual feedback confirms accurate alignment and completion of the scanning process. After all guides on one side have been scanned and verified, the software determines the three-dimensional positions of the screws and calculates the distances between the screw heads. Based on these measurements, a patient-specific rod template is generated that precisely matches the required rod length and curvature by following the trajectory through each screw head in both the sagittal and coronal planes. The template is displayed on the iPad at a 1:1 scale, enabling accurate cutting and contouring of the rods (Fig. 2). The same procedure is subsequently repeated on the contralateral side. Markers on the set-screw driver indicate whether the rod is seated in a stress-free position within all screw heads following preliminary tightening” (27).

Outcome measures

The primary endpoint of the study was procedural feasibility and safety of AR-assisted rod contouring.

Secondary endpoints included implant-related complications, such as intraoperative screw pullout, postoperative screw loosening, rod fracture or hardware failure, reoperation related to instrumentation, pain intensity assessed using the Visual Analogue Scale (VAS) and functional disability assessed using the Oswestry Disability Index (ODI).

Intraoperative fluoroscopic imaging was obtained after pedicle screw insertion and again following rod implantation to assess pedicle screws integrity and identify potential screw pullouts during rod placement. All patients underwent postoperative computed tomography (CT) within 24 hours after surgery. CT imaging was used to evaluate pedicle screw accuracy according to the Gertzbein–Robbins classification and to identify early implant-related complications.

At three months postoperatively, standard standing radiographs were obtained to assess construct stability and detect evidence of screw loosening, rod failure, implant migration, or hardware disassembly.

Pain intensity was assessed using the Visual Analogue Scale (VAS). Functional outcome was evaluated using the Oswestry Disability Index (ODI). Assessments were performed preoperatively, on postoperative day 5, and at three-month follow-up. Clinical outcomes were additionally categorized using the modified MacNab criteria.

Statistical analysis

Statistical analyses were performed using GraphPad Prism Version 10 (GraphPad Software, San Diego, CA, USA). A two-sided p-value of < 0.05 was considered statistically significant.

Baseline demographic and clinical characteristics of the study population were summarized using descriptive statistics. Continuous variables, including age, body mass index (BMI), and outcome measures such as Visual Analog Scale (VAS) scores and Oswestry Disability Index (ODI), were reported as means with standard deviations (SD). Categorical variables, including sex, comorbidities such as arterial hypertension or diabetes mellitus, and use of anticoagulant medication, were presented as frequencies and percentages.

Associations between postoperative outcomes (VAS and ODI) and patient-specific variables (BMI, age, sex, comorbidities, and anticoagulant use) were evaluated using univariable analyses (Pearson correlation, Mann–Whitney U test and One-way ANOVA). To identify independent predictors of postoperative pain and disability, multivariable linear regression models were constructed with VAS and ODI scores as dependent variables.

Results

Patient characteristics

Twenty patients (9 females, 11 males) with a mean age of 71.6 ± 6.7 years (range 54–79) were included. The mean BMI was 27.4 ± 4.2 kg/m².

The comorbidities of the patients were: arterial hypertension (70%), Diabetes mellitus type II (15%), use of anticoagulants (35%). Only 10% of the patients were smokers with an average of 9.5 pack-years. No patients declared to have osteoporosis.

Preoperative pain, assessed using the Visual Analog Scale (VAS), averaged 8.02 ± 0.9 points. The Oswestry Disability Index (ODI) preoperatively was 69.2 ± 8.5 points.

Posterior thoracolumbar instrumentation was performed at a medina of 4 spinal levels (range 3–7 segments) from T11 to S1. The pathologies were degenerative spinal disease in 19 patients (95%) and fracture in one patient (5%). A total of 206 pedicle screws in the thoracolumbar spine were implanted (average 10 screws per patient). We implanted intervertebral cages in all the pedicle screw fixation for degenerative spinal diseases.

A total of 40 rods were used and bent with the assistance of the augmented reality-bending software. The length of the rod was 139.6 ± 31.2 mm.

All procedures were successfully completed using the augmented reality–rod bending software ADVISE (Neo Medical, Switzerland). There were no complications related to this device.

Surgical outcomes

Mean operative time was 349.9 ± 96.6 minutes, with intraoperative blood loss averaging 1170 ± 407 ml.

The time needed from connecting the detachable guides in the screws-heads to generate the rod template in the iPad screen took 3 to 5 min. Mean 3.5 ± 1.2 min.

The mean postoperative hospital stay was 8.3 ± 3.1 days.

A marked reduction in the VAS scores was observed as early as postoperative day 5 from 8.02 to 6.45 ± 1.2 points ($p < 0.001$). At 3 months, mean VAS scores decreased to 4.0 ± 0.8 points ($p < 0.001$) (see Fig. 3).

The ODI also demonstrated continuous improvement with 62.7 ± 11.6 points on day 5, and 45.6 ± 9.6 points at 3 months ($p < 0.001$) (see Fig. 4).

Postoperative clinical outcomes assessed using the McNab criteria showed that, at day 5: 7 patients (35%) had a “poor” improvement, 9 patients (45%) a “fair” improvement, while 4 patients (20%) were rated as “good.” At 3 months, 8 patients (40%) achieved a “fair” outcome, and 12 patients (60%) achieved a “good” or “excellent” outcome.

Postoperative CT imaging demonstrated accurate pedicle screw placement in all cases. According to the Gertzbein–Robbins classification, all implanted screws were classified as Grade A or Grade B.

Comparison of intraoperative fluoroscopic images obtained before and after rod insertion revealed no evidence of screw displacement or intraoperative screw pullout.

The AR-assisted workflow enabled rod insertion without the need for rod reduction manoeuvres in all patients.

Complications

No cases of pedicle screw loosening, rod fracture, implant migration, construct disassembly, or instrumentation-related revision surgery were observed during the three-month follow-up period.

Radiographic evaluation demonstrated stable constructs in all patients. No complications directly attributable to the AR-assisted rod contouring system were encountered. No other complications were detected.

Discussion

The present study provides the first prospective clinical evaluation of augmented reality (AR)–assisted rod alignment in multilevel thoracolumbar fixation. The principal finding was that the use of the ADVISE AR-supported rod bending workflow was feasible in all patients and was not associated with intraoperative screw pullout, implant-related technical failure, or early construct loosening during the short-term follow-up period. To generate the rod template with the AR-ADVISE software is really quick, taking up to five minutes. This constitutes a time-saving step, with a lot of benefits and no disadvantages.

Pedicle screw fixation remains the gold standard for thoracolumbar fixation; however, implant-related complications continue to represent a major limitation, particularly in multilevel instrumentation and elderly patients. Previous studies have demonstrated screw loosening rates ranging from 20% to over 50% (15, 17–19), especially in osteoporotic bone and long-segment constructs. Mechanical overload generated during rod reduction has been identified as an important contributing factor to screw loosening and pullout (21–25). Even small mismatches between screw head position and rod contour may generate substantial corrective forces during final rod seating.

An additional observation was the excellent radiographic accuracy of pedicle screw placement. All screws were classified as Grade A or Grade B according to the Gertzbein–Robbins classification. Accurate screw placement is a prerequisite for successful rod alignment and construct stability. Although screw accuracy was not a primary endpoint of the present study, the combination of accurate screw placement and patient-specific rod contouring may represent a complementary strategy for optimizing construct assembly.

Traditional rod contouring is largely based on the surgeon’s experience and visual estimation. Consequently, repeated bending adjustments and forceful rod reduction maneuvers are frequently necessary. These maneuvers may increase stress at the bone–implant interface. Accurate rod alignment plays an important role in reducing internal forces within pedicle screw constructs. Previous biomechanical studies have demonstrated that rod–screw mismatch can generate considerable internal forces that may compromise the bone–implant interface and increase the risk of pedicle screw loosening or pullout (21, 29).

Forced rod fixation to compensate for misalignment may introduce additional mechanical stress within the instrumentation system and lead to asymmetric load distribution (21). In contrast, the use of augmented reality visualization in the present study aimed to facilitate accurate rod alignment and consequently avoid mechanical stress in the rod fixation which leads to screw pullout. By providing a three-dimensional representation of the screw–rod relationship, the AR ADVISE software allows surgeons in achieving more accurate rod contouring and alignment with no reduction force needed.

Our findings are consistent with previous biomechanical and technical studies suggesting that optimized rod alignment may reduce implant-related stress (21, 24, 28). Earlier investigations demonstrated that

computer-assisted rod bending systems can decrease screw pullout forces and improve construct alignment compared with conventional freehand bending techniques (22). However, clinical evidence regarding AR-assisted rod bending has been lacking. The present study therefore provides important preliminary clinical data supporting the feasibility of this technology.

Notably, from the total of the 206 pedicle screws and 40 roads implanted, no cases of screw pullout, screw loosening, rod breakage, or other complications were identified radiographically during short-term follow-up. This finding is particularly relevant considering the advanced age of the cohort and the multilevel nature of the instrumentation. Furthermore, all planned constructs could be completed without abandoning the AR workflow or requiring major intraoperative modification.

Significant improvements were observed in both pain and functional disability scores. Mean VAS and ODI values improved progressively throughout the postoperative period and reached statistical significance at three months. These findings are consistent with previously reported outcomes following multilevel thoracolumbar decompression and fusion procedures. Nevertheless, the observed clinical improvement should be interpreted cautiously, as it cannot be attributed exclusively to the AR-assisted workflow.

From a practical perspective, implementation of the AR-assisted workflow was straightforward and required only three to five additional minutes following pedicle screw placement. No software-related complications, technical failures, or interruptions of the surgical workflow were encountered. These findings suggest that the technology may be integrated into routine clinical practice without substantially increasing operative complexity.

The potential long-term benefits of AR-assisted rod contouring remain speculative. Although it is reasonable to hypothesize that improved rod–screw alignment may reduce mechanical stress within the construct, the present study was not designed to evaluate long-term implant survival, pseudarthrosis, adjacent segment degeneration, or revision surgery. Demonstration of such benefits will require larger comparative studies with extended follow-up periods.

Conclusions

This augmented reality-supported rod bending system is a novel tool that allows an optimized alignment of the pedicle screws and rod. This may avoid external forces in the hardware, which can lead to screw pullout, screw loosening and other complications that result in more postoperative pain for the patients, complications and less life quality. The software allows controlled fixation instead of forced fixation.

Intraoperatively there were no complications observed, demonstrating that controlled fixation is related to less hardware failures.

We demonstrated that in a short-term period of three months after surgery, the patients improved significantly with pain reduction and better life quality.

Limitations

Some limitations should be acknowledged when interpreting the results of this study.

First, the sample size was relatively small, reflecting the pilot nature of the investigation. Consequently, the study was not powered to detect uncommon complications or small differences in clinical outcomes. Second, the study was conducted at a single institution and lacked a control group undergoing conventional rod contouring. Therefore, direct comparisons between AR-assisted and conventional workflows cannot be made. Third, the follow-up period was limited to three months. While no implant-related complications were observed during this period, longer follow-up is necessary to assess screw loosening, pseudarthrosis, rod fracture, adjacent segment disease, and revision surgery. Fourth, the study did not include direct biomechanical measurements of rod–screw mismatch, construct forces, or stress distribution. Accordingly, any proposed biomechanical advantages remain theoretical and should be interpreted as hypotheses requiring further investigation.

Despite these limitations, the present study provides the first prospective clinical data regarding AR-assisted rod contouring in thoracolumbar instrumentation and establishes a foundation for future comparative investigations.

Declarations

Informed consent statement

The study was conducted at the Department of Neurosurgery, Bayreuth Hospital, Medical Campus of Friedrich-Alexander-University Erlangen-Nuremberg, Upper Franconia. Ethical approval was obtained from the Ethics Committee of Friedrich-Alexander-University Erlangen-Nuremberg (No. 25-20 Bm).

The study was registered in the German Clinical Trials Register (ID: DRKS00039841).

The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all patients.

Conflict of interest

This study was facilitated thanks to Neo Medical SA (Villette, Switzerland), who borrowed the ADVISE Software tablet for the study period. The company had no role in study design, patient selection, data collection, statistical analysis, manuscript preparation, or the decision to submit the manuscript for publication.

The authors declare that they have no competing financial interests related to this study.

Funding

This work was supported by internal research funding from Bayreuth Hospital, Germany (Project No. 50 041). The funding source had no involvement in study design, data acquisition, data interpretation, manuscript preparation, or publication decisions.

Author Contribution

Conceptualization: B.RM, C.S, SL. Methodology: B.RM, C.S. Validation: F.K.. S.S. Formal analysis: S.A., S.L. Investigation: B. RM., C.S. F.K., Writing: B.RM, F.K. Review and Editing: B.RM, C.S., S.L. Supervision: S.L., C.S.

References

1. Amadi IJ, Kabangu JLK, Bhargav AG, Camarata PJ (2024) The Legacy of Harrington's Rod and the Evolution of Long-Segment Constructs in Spine Surgery. J Clin Med 19 September 13(18):5556. 10.3390/jcm13185556
2. Cho SK, Kim YJ (2011) History of Spinal Deformity Surgery Part I: The Pre-modern Era. Korean J Spine 8(1):1. 10.14245/kjs.2011.8.1.1
3. Roy-Camille R, Saillant G, Mazel C (1986) Internal fixation of the lumbar spine with pedicle screw plating. Clin Orthop Februar ;(203):7–17. PubMed PMID: 3955999.
4. Tukkapuram VR, Kuniyoshi A, Ito M (2019) A Review of the Historical Evolution, Biomechanical Advantage, Clinical Applications, and Safe Insertion Techniques of Cervical Pedicle Screw Fixation. Spine Surg Relat Res 27 April 3(2):126–135. 10.22603/ssrr.2018-0055
5. Matsukawa K, Yato Y (2017) Lumbar pedicle screw fixation with cortical bone trajectory: A review from anatomical and biomechanical standpoints. Spine Surg Relat Res 1(4):164–173. 10.22603/ssrr.1.2017-0006
6. Ye YX, Huang DG, Hao DJ, Liu JY, Ji JJ, Guo JN (2023) Screw Pullout Strength After Pedicle Screw Reposition: A Finite Element Analysis. Spine 15 November 48(22):E382–E388. 10.1097/BRS.0000000000004553
7. Boos N, Webb JK (1997) Pedicle screw fixation in spinal disorders: A European view. Eur Spine J Januar 6(1):2–18. 10.1007/BF01676569
8. Mensah EO, Chalif JI, Baker JG, Chalif E, Biundo J, Groff MW (2024) Challenges in Contemporary Spine Surgery: A Comprehensive Review of Surgical, Technological, and Patient-Specific Issues. J Clin Med 14 September 13(18):5460. 10.3390/jcm13185460
9. Wang Y, Kahaer A, Maimaiti A, Guo H, Rexiti P (2023) Complication, fusion, and revision rate in the lumbar cortical bone trajectory and pedicle screw fixation techniques: a systematic review and meta-analysis. J Orthop Surg 25 Mai 18(1):382. 10.1186/s13018-023-03820-7
10. Pitter FT, Lindberg-Larsen M, Pedersen AB, Dahl B, Gehrchen M (2019) Revision Risk After Primary Adult Spinal Deformity Surgery: A Nationwide Study With Two-Year Follow-up. Spine Deform Juli

7(4):619–626e2. 10.1016/j.jspd.2018.10.006

11. Sawa AGU, Wangsawatwong P, Lehrman JN, Hostetler T, De Andrada Pereira B, Godzik J (2023) u. a. Rod Attachment Induces Significant Strain in Lumbosacral Fixation. Clin Spine Surg Juli 36(6):E247–E251. 10.1097/BSD.0000000000001438
12. Miller CA, Ledonio CG, Hunt MA, Siddiq F, Polly DW (2016) Reliability of the Planned Pedicle Screw Trajectory versus the Actual Pedicle Screw Trajectory using Intra-operative 3D CT and Image Guidance. Int J Spine Surg 10:38. 10.14444/3038
13. Ardura F, Chenaux D, Pascal-Moussellard H, Hessmann MH (2021) Evaluation of the reduction, tightening and gripping performance of an innovative set screw technology for instrumented posterior lumbar fusion: A biomechanical study. Orthop Traumatol Surg Res November 107(7):102918. 10.1016/j.otsr.2021.102918
14. Rana M, Biswas JK, Roy S, Ghosh N, Bhattacharya S, Karmakar SK (2020) u. a. Measurement of strain in the rod for lumbar pedicle screw fixation: An experimental and finite element study. Biomed Phys Eng Express 1 November 6(6):065035. 10.1088/2057-1976/abc607
15. Bokov A, Bulkin A, Aleynik A, Kutlaeva M, Mlyavykh S (2019) Pedicle Screws Loosening in Patients With Degenerative Diseases of the Lumbar Spine: Potential Risk Factors and Relative Contribution. Glob Spine J Februar 9(1):55–61. 10.1177/2192568218772302
16. Mid-range outcomes (2010) in 64 consecutive cases of multilevel fusion for degenerative diseases of the lumbar spine. Orthop Rev 20 März 2(1). 10.4081/or.2010.e3
17. Wu Zxiang, Gong F tai, Liu L, Ma Z sheng, Zhang Y, Zhao X et al (2012) A comparative study on screw loosening in osteoporotic lumbar spine fusion between expandable and conventional pedicle screws. Arch Orthop Trauma Surg. April ;132(4):471–6. 10.1007/s00402-011-1439-6
18. Galbusera F, Volkheimer D, Reitmaier S, Berger-Roscher N, Kienle A, Wilke HJ (2015) Pedicle screw loosening: a clinically relevant complication? Eur Spine J Mai 24(5):1005–1016. 10.1007/s00586-015-3768-6
19. Kim DH, Hwang RW, Lee GH, Joshi R, Baker KC, Arnold P (2020) u. a. Comparing rates of early pedicle screw loosening in posterolateral lumbar fusion with and without transforaminal lumbar interbody fusion. Spine J September 20(9):1438–1445. 10.1016/j.spinee.2020.04.021
20. Ohba T, Ebata S, Oba H, Koyama K, Haro H (2019) Risk Factors for Clinically Relevant Loosening of Percutaneous Pedicle Screws. Spine Surg Relat Res 25 Januar 3(1):79–85. 10.22603/ssrr.2018-0018
21. Loenen ACY, Noriega DC, Ruiz Wills C, Noailly J, Nunley PD, Kirchner R (2021) u. a. Misaligned spinal rods can induce high internal forces consistent with those observed to cause screw pullout and disc degeneration. Spine J März 21(3):528–537. 10.1016/j.spinee.2020.09.010
22. Ohba T, Ebata S, Oda K, Tanaka N, Haro H (2021) Utility of a Computer-assisted Rod Bending System to Avoid Pull-out and Loosening of Percutaneous Pedicle Screws. Clin Spine Surg April 34(3):E166–E171. 10.1097/BSD.0000000000001099

23. Von Atzigen M, Liebmann F, Cavalcanti NA, Anh Baran T, Wanivenhaus F, Spirig JM (2024) u. a. Reducing residual forces in spinal fusion using a custom-built rod bending machine. Comput Methods Programs Biomed April 247:108096. 10.1016/j.cmpb.2024.108096
24. Noriega DC, Ardura F, Awad K, Hajdari S, Sánchez Lite I, Abdalla Y (2025) Is Force Control a Safe and Efficient Surgical Technology for Thoracolumbar Fusion Surgery? A Post Market Clinical Follow-Up Study. World Neurosurg April 196:123812. 10.1016/j.wneu.2025.123812
25. Noriega DC, Eastlack RK, Hernández GL, Kafchitsas K, Ryang YM, Spitz SM (2024) u. a. Does the interfacing angle between pedicle screws and support rods affect clinical outcomes after posterior thoracolumbar fusion? A retrospective clinical study. Spine J Januar 24(1):125–131. 10.1016/j.spinee.2023.09.008
26. Serhan H, Hammerberg K, O'Neil M, Sturm P, Mardjetko S, Crawford A (2010) Intraoperative Techniques to Reduce the Potential of Set-screw Loosening in Long Spinal Constructs: A Static and Fatigue Biomechanical Investigation. J Spinal Disord Tech Oktober 23(7):e31–e36. 10.1097/BSD.0b013e3181c982a1
27. Antes S, Moringlane R, Von Eckardstein KL (2023) Augmented Reality-Supported Rod Bending in Multilevel Spinal Fusion Using the ADVISE Software. World Neurosurg Oktober 178:96–100. 10.1016/j.wneu.2023.07.029
28. Abdalla Y, Hajdari S (2023) New approaches to proven technology: Force control posterior thoracolumbar fusion with an innovative pedicle screw system. Interdiscip Neurosurg März 31:101701. 10.1016/j.inat.2022.101701
29. Wagnac E, Michardière D, Garo A, Arnoux PJ, Mac-Thiong JM, Aubin CE (2010) Biomechanical analysis of pedicle screw placement: a feasibility study. Stud Health Technol Inf 158:167–171 PubMed PMID: 20543418

Figures

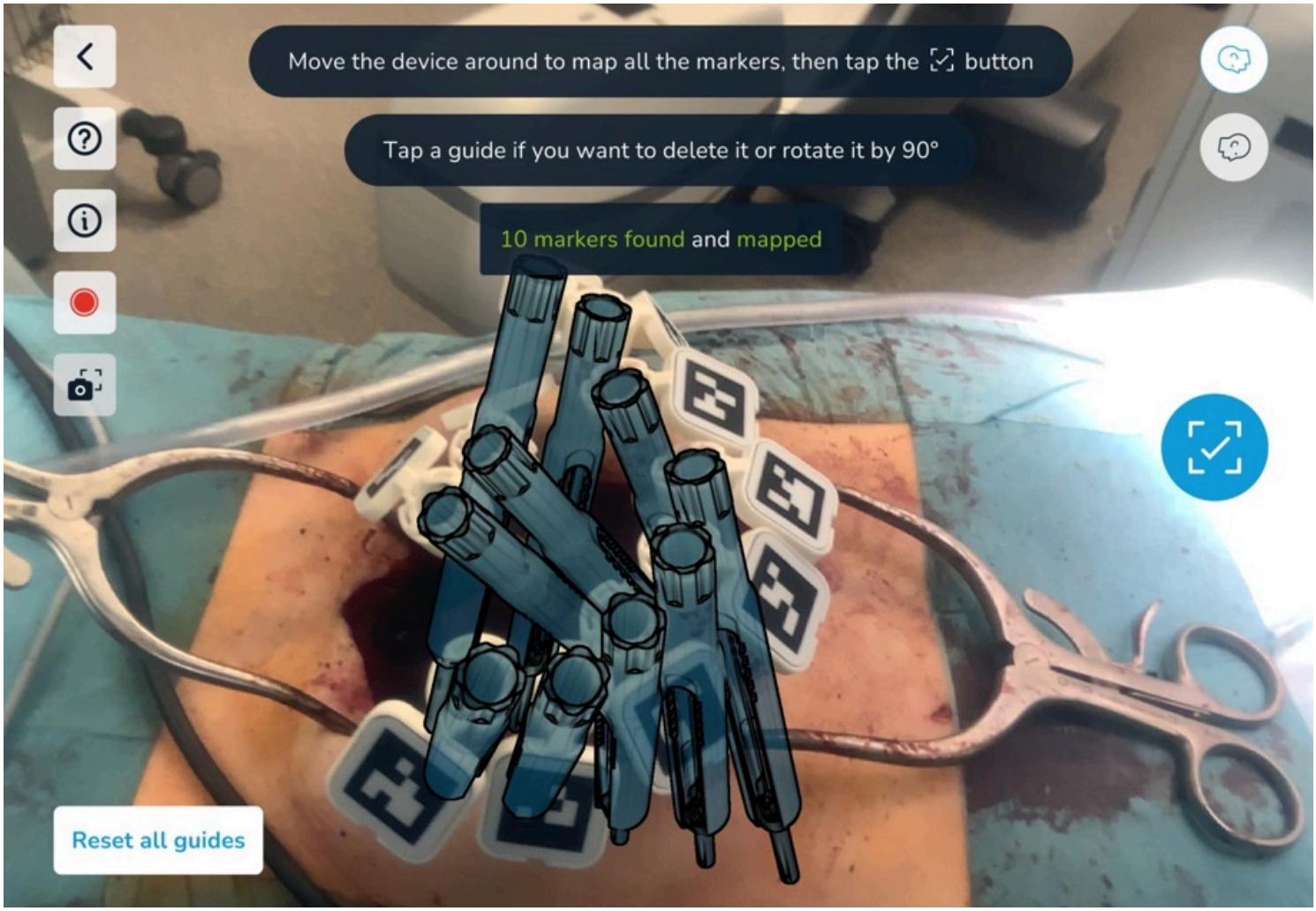


Figure 1

Live three-dimensional scanning with the ADVISE software.

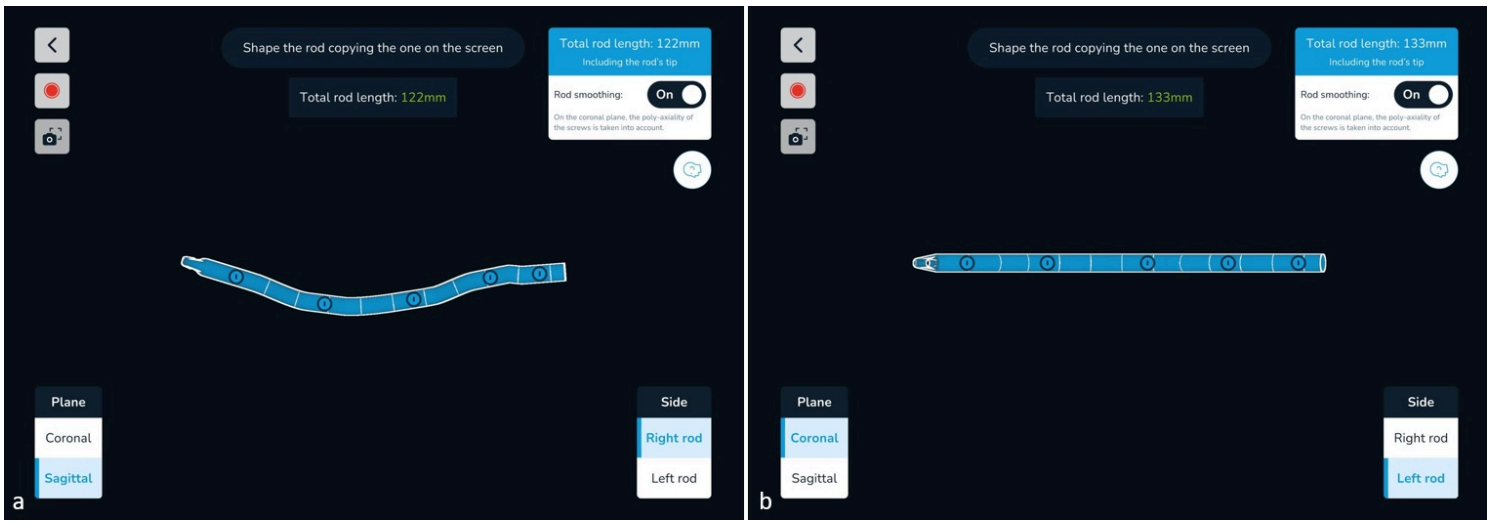


Figure 2

Generated rod after three-dimensional scanning in a 1 to 1 scale. A) sagittal view. B) coronal view.

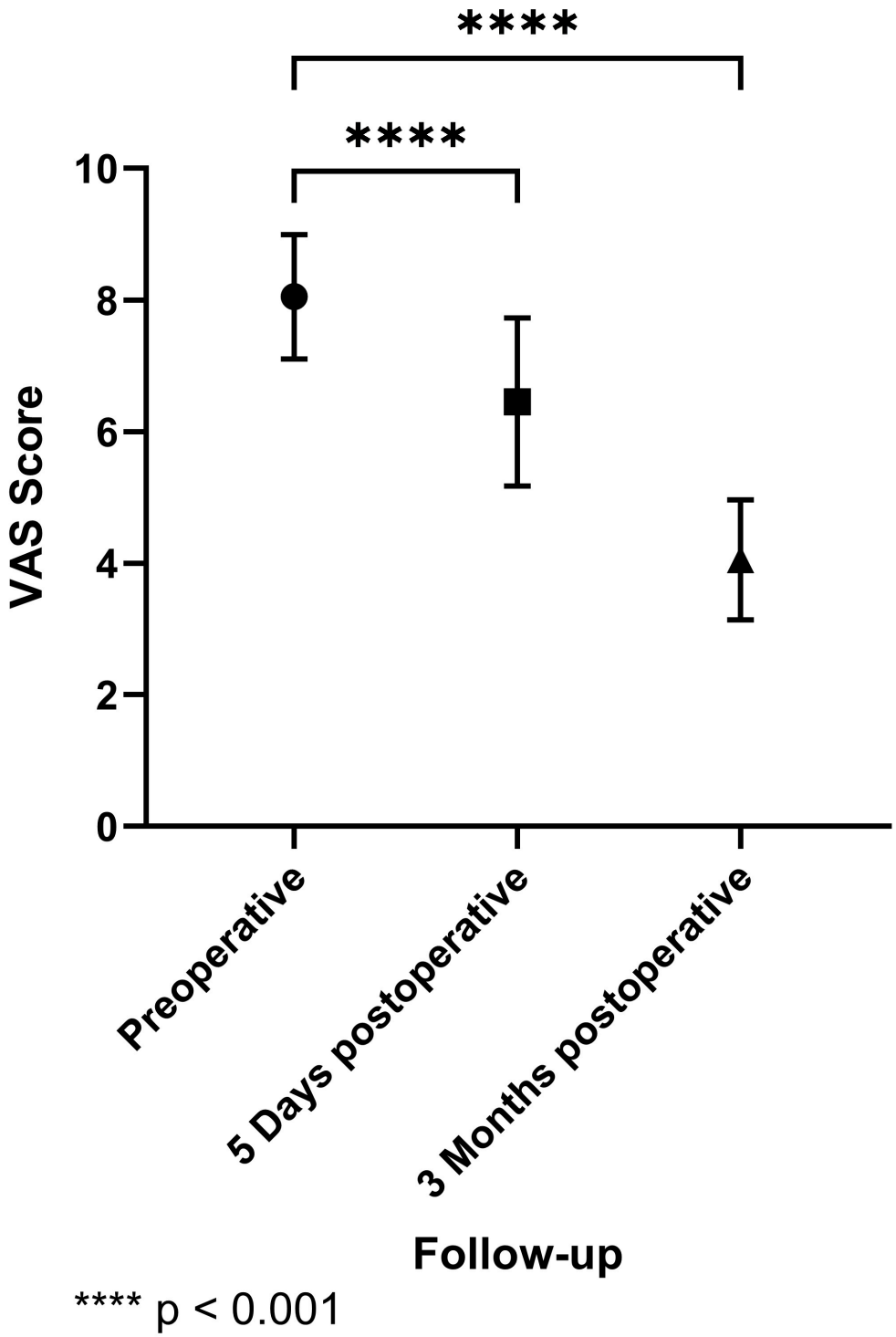


Figure 3

Visual Analog Scale (VAS) average from the patients before the operation, five days later and three months later. Statically significant reduction of the VAS score after three months.

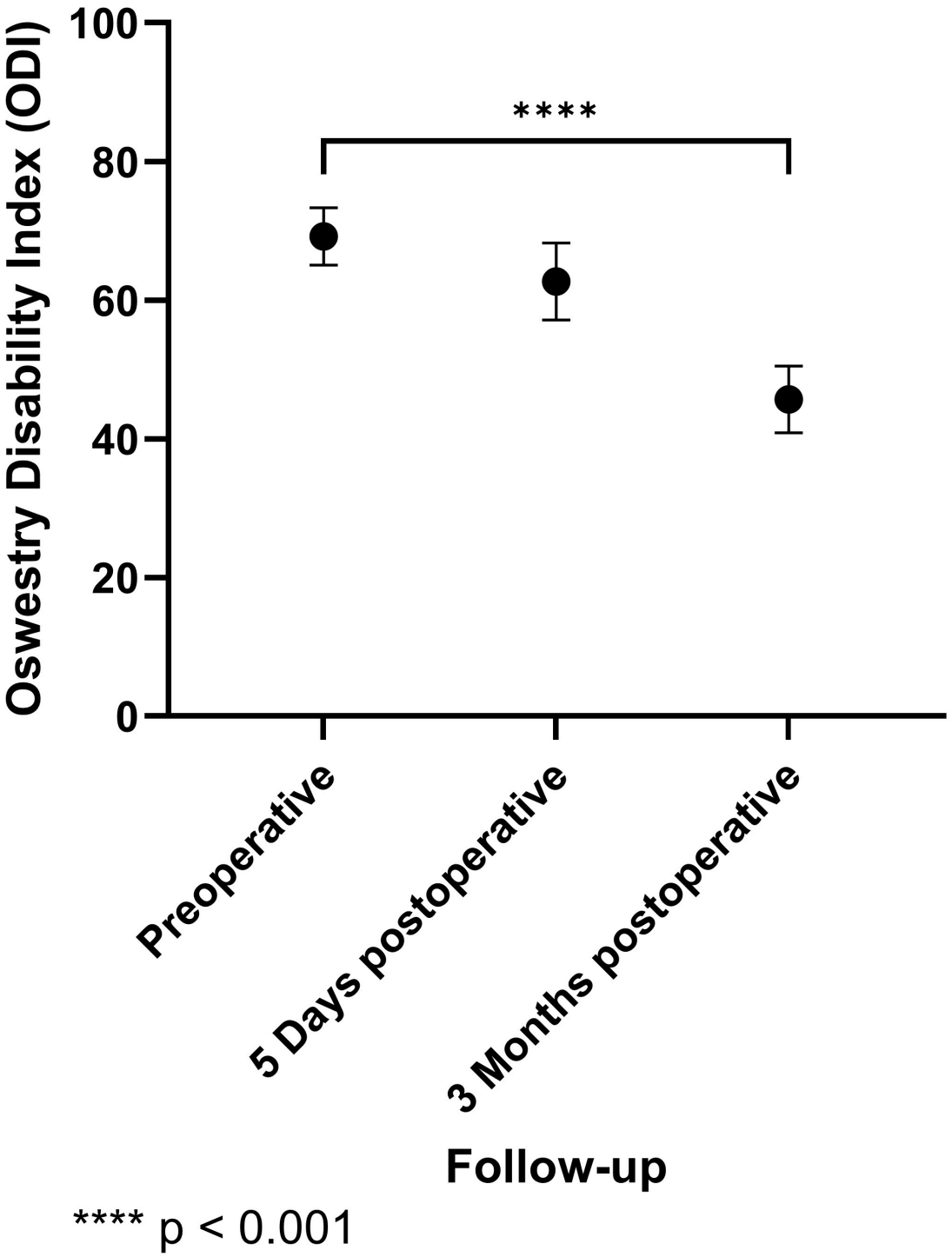


Figure 4

The Oswestry Disability Index (ODI) average before the operation, five days later and three months later. Statically significant reduction of the ODI score five days and three months after operation.