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Rod persuading reduces primary construct stability in lumbar interbody fusion in the osteoporotic spine – A biomechanical in-vitro study

Vincent J. Heck [a], Tobias Prasse [a], Juan Manuel Vinas-Rios [a,b,*], Andreas Prescher [c], Lajos Basten [d], Maximilian Weber [a], Peer Eysel [a], Nikolaus Kernich [a]

[a] Faculty of Medicine and University Hospital Cologne, Department of Orthopedics, Trauma and Plastic Surgery, University of Cologne, Kerpener Str. 62, 50937 Cologne, Germany.
[b] Faculty of Medicine UASLP, San Luis Potosi, Mexico
[c] Institute of Molecular and Cellular Anatomy, RWTH Aachen University Hospital, Wendlingweg 2, 52070 Aachen, Germany
[d] Faculty of Medicine and University Hospital Cologne, Department of Diagnostic and Interventional Radiology, University of Cologne, Kerpener Str. 62, 50937 Cologne, Germany.

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ABSTRACT

Background: With the introduction of the pedicle screw-rod system and intervertebral cages, posterior spinal fusion has increasingly become a standard procedure in the treatment of degenerative spinal conditions.
The aim of this study is to investigate the influence of rod persuading in lumbar spinal fusion constructs on the pullout strength of pedicle screws, considering different bone qualities.
Methods: Ten fresh-frozen lumbar spines (L1–5) from 10 cadaveric donors were initially included. All specimens were examined at the beginning of the study both macroscopically and by computed tomography scans (HR-CT, Siemens) to ensure specimen integrity, and the mineral bone density by using Hounsfield units. One specimen had to be excluded prior to biomechanical testing due to a vertebral fracture extending into the pedicle, leaving a total of 9 specimens available for the study.
Findings: The displacement of the screws during the pullout test was significantly greater in the osteoporotic specimens after rod persuader use (Group 2), compared to the non-osteoporotic specimens (3.7 ± 0.7 mm vs. 5.5 ± 0.4 mm, $p = 0.0486$). This difference was not observed in the non-rod persuader group. Overall, rod persuading decreased the displacement distance until tensile load to screw failure by 29 %.
Interpretation: The use of the rod persuader reduces the pedicle screw pullout strength, thereby compromising the construct stability. This reduction is particularly significant in osteoporotic vertebral bodies, highlighting the need for careful consideration of rod persuader use in this patient population.

1. Introduction

With the introduction of the pedicle screw-rod system and intervertebral cages, posterior spinal fusion has become a standard procedure in the treatment of degenerative spinal conditions (Reid et al., 2019). Due to rising global life expectancy, coupled with high expectations for mobility in advanced age, and the widespread availability of modern medical procedures for the broad public across many countries, a continuous increase in the number of lumbar spinal fusions performed could be noted (Deyo et al., 2005; Martin et al., 2019). This trend is expected to continue, particularly driven by an increasing number of future geriatric patients (Heck et al., 2023). On one hand, this enables many patients to maintain good mobility and a high quality of life. On the other hand, the advancing age of the patient population is expected to lead to a higher number of patients suffering from osteoporosis, which is considered the most important risk factor for implant-related complications such as screw loosening (Fig. 1)in posterior spinal fusions due to reduced bone quality (Galbusera et al., 2015; Lonstein et al., 1999; Zou et al., 2020a).

A common issue in spinal surgery is the mismatch between rigid pedicle screws and the semi-rigid titanium rods. The Rod Persuader (RP) addresses this by allowing the pedicle screw and rod to be brought

* Corresponding author at: Faculty of Medicine and University Hospital Cologne, Department of Orthopedics, Trauma and Plastic Surgery, University of Cologne, Kerpener Str. 62, 50937 Cologne, Germany.
E-mail address: vinasrios@outlook.com (J.M. Vinas-Rios).

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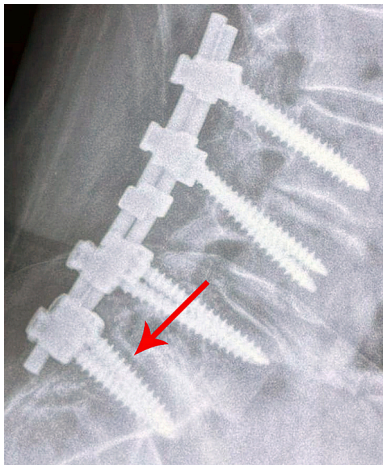

Fig. 1. Lateral x-ray depicting a radiolucent line around the screws S1 indicating a lack of bony contact according with screw loosening (⬆) in a patient after rod persuading in a patient with a lumbar fusion L3 to S1.

together through axial tension at the screw head, enabling the construct to be secured with a set screw. This technique facilitates the correction of complex spinal deformities or the reduction of anterior spondylolisthesis to a posterior position, ultimately to restore spinal alignment. Furthermore, rod persuading allows for the fitting of a non-precisely contoured rod into the pedicle screw head without the need for repeated rod removal and external bending, thereby reducing operative time. However, clinical experience suggests that the forces involved may reduce the overall construct stability of the screw-rod system, particularly the pullout strength of the pedicle screws. Despite this concern, few biomechanical studies have examined this technique, and there is a lack of data on the impact of pedicle screw pullout strength in patients with varying bone quality undergoing lumbar spinal fusion (Kang et al., 2015; Kernich et al., 2024; Paik et al., 2013).

The aim of this study is to investigate the influence of rod persuading in lumbar spinal fusion constructs on the pullout strength of pedicle screws, considering different bone qualities.

2. Methods

2.1. Specimens

For this study, 10 fresh-frozen lumbar spines (L1–5) from 10 cadaveric donors were initially included. All specimens were examined at the beginning of the study both macroscopically and by computed tomography (CT) scan (HR-CT, Siemens) to ensure their integrity, and the mineral bone density (MBD) was assessed using Hounsfield units (HU) (Scheyerer et al., 2019). One specimen had to be excluded prior to biomechanical testing due to a vertebral fracture including the pedicle, leaving a total of 9 specimens available for the study. The specimens were stored at −20 °C and thawed at room temperature for 24 h immediately before the start of the biomechanical testing. Subsequently, careful preparation was performed, including the removal of soft tissue and musculature.

2.2. Preparation for biomechanical testing

A three-level transforaminal lumbar interbody fusion (TLIF) of the L3–5 segments was first performed using the Roccia Multi-LIF Cage (Silony Medical, Leinfelden-Echterdingen, Germany). Pedicle screws (6.5 × 50 mm, Medtronic Inc., Minneapolis, MN, USA) were implanted under fluoroscopic guidance (Fig. 2 and Fig. 3). The specimens were then randomized into two groups for the left and right sides. On one side (Group 1), the titanium rod was bent such that, after fixation to the pedicle screws at the fourth and fifth lumbar vertebrae, a 5 mm gap remained between the pedicle screw of the third lumbar vertebra and the rod. Using a RP, the rod was then pushed into the pedicle screw, and the set screw was inserted. The screw-rod construct was left in place for 30 min, after which the rod was removed. On the contralateral side (Group 2), the titanium rod was inserted tension. The set screws were then implanted without the assistance of a rod persuader, allowing the rod to be kept in place with minimal tension. As in Group 1, the screw-rod construct was left in place for 30 min before the rod was removed (Fig. 4).

2.3. Determination of axial pullout strength

After rod removal, the third lumbar vertebra was carefully dissected and entirely cleared of soft tissues, including the adjacent intervertebral discs and ligaments. Meticulous care was taken to avoid any

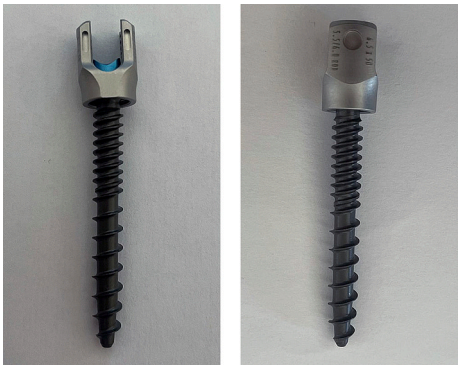

Fig. 3. Image of the pedicle screw used in the study (6.5 × 50 mm, Medtronic Inc., Minneapolis, MN, USA).

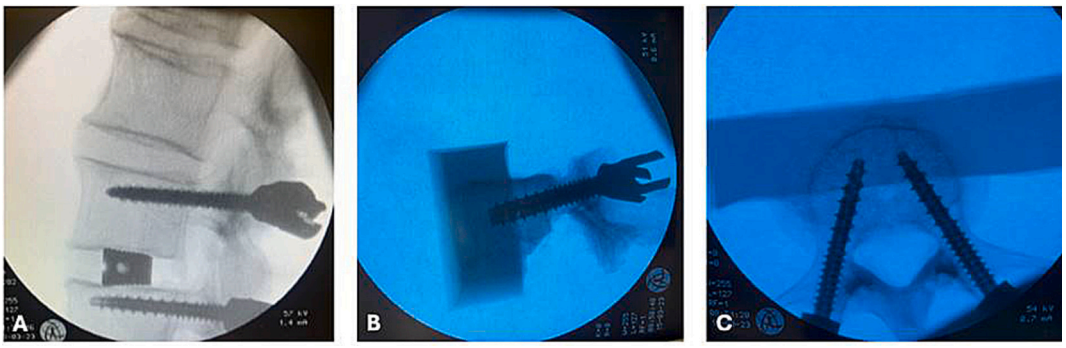

Fig. 2. (A) Vertebral bodies L2, L3 and L4 during bisegmental spondylodesis of L3 to 5 prior to connection with the rod in lateral fluoroscopic view. **(B)** Verification of the screw position in the L3 vertebral body after embedding in PMMA, shown in the lateral view, and **(C)** in the craniocaudal fluoroscopic view.

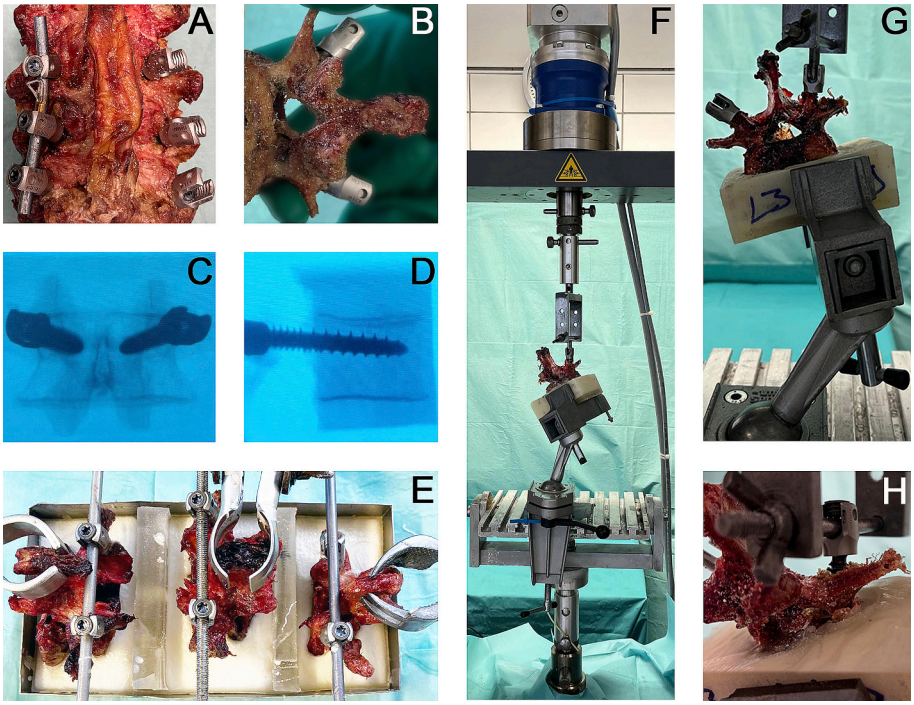

Fig. 4. Biomechanical testing setup. **(A)** Posterior view of the L3–L5 spinal fusion. On the left side, the titanium rod with set screws has already been implanted. On the contralateral side (control group), the rod will be implanted afterwards,. After 30 min, the rod is removed, and the L3 vertebra is dissected free of soft tissue, without manipulating the pedicle screws. **(B)**The vertebral body fully prepared for biomechanical testing. **(C)** Anteroposterior fluoroscopic representation of the L3 Vertebra. **(D)** Lateral fluoroscopic representation of the L3 Vertebra. **(E)** Prior image showing the L3 vertebrae from three different donors during the curing process in PMMA. After curing, the vertebrae are sectioned. **(F)** Representation of the axial pull-out test using the testing machine. All vertebrae are tested strictly in axial direction to ensure comparability. The testing machine records both displacement and force during testing. **(G)** Close up view of the testing machine records. **(H)** Representation of the axial pull-out in vitro.

manipulation of the implanted pedicle screws. The anterior two-thirds of the vertebral body were then embedded in polymethyl methacrylate (PMMA, Technovit 4004, Heraeus Kulzer GmbH, Wehrheim, Germany) to ensure a secure fit in the testing machine (Fig. 5). Once the PMMA had hardened, the pullout strength of both pedicle screws was measured. The PMMA-embedded vertebral body was mounted in a servo-hydraulic universal testing machine (Zo10, Zwick/Roell, Ulm, Germany) such that the pedicle screw could be subjected to strictly axial tensile loading to failure (Fig. 6A). In accordance with previous studies, the tensile load was applied at a rate of 0.25 mm per second. The corresponding force was recorded in Newton (N), with screw pullout defined as a sudden 5 % drop in force (Fig. 6B).

2.4. Ethics

This study was conducted with the approval of the responsible ethics committee (No. 23–1417). All procedures performed in this study involving human cadaveric specimens were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

2.5. Statistical analysis

Statistical analysis was performed using Microsoft Excel (Microsoft® Excel, Version 16.85), JMP (JMP Statistical Software, Version 15.0, Statistical Discovery, LLC, Cary, NC, USA), and Prism 7 (GraphPad Software, LLC, Sang Diego, CA, USA). Depending on the distribution of the values, the mean and standard deviation or median and interquartile range (IQR) were determined. Normally distributed data were analyzed using Student's *t*-test, while non-normally distributed data were compared using the Wilcoxon-Mann-Whitney *U* test for group differences. Categorical variables were analyzed using the chi-square test, for small groups Fisher's exact test was applied. A *p*-value of less than 0.05 was considered statistically significant.

3. Results

The average age of the body donors was 87 years (range: 76 to 96 years). The average HU of the vertebral bodies was 138.9 ± 75.7. Four vertebral bodies had a BMD of less than 100.8, with an average of 72 (range: 62.1 to 84.1), and were classified as osteoporotic. Five vertebral bodies were non-osteoporotic, with an average BMD of 192.4 (range: 104.5 to 281.5).

The average pullout force of the pedicle screws within all specimens was 505 ± 212 N. The pullout force of the pedicle screws in osteoporotic specimens was significantly reduced after the use of the RP (Group 2) compared to non-osteoporotic specimens (298 ± 55 N vs. 503 ± 63 N, $p = 0.0483$) (Fig. 7). This difference was not observed in the control group (Group 2), in which the titanium rod was implanted tension-free (Table 1). Overall, the pullout strength was reduced by 31 % after the use of the RP, but this difference was not statistically significant (412 ± 54 N vs. 599 ± 78 N, $p = 0.0671$).

The displacement of the screws during the pullout test was significantly greater in the osteoporotic specimens after use of the RP (Group 2), compared to the non-osteoporotic specimens (3.7 ± 0.7 mm vs. 5.5 ± 0.4 mm, $p = 0.0486$) (Fig. 8). This difference was not observed in the non-RP group (Table 2). Overall, rod persuading decreased the displacement distance until tensile load to screw failure by 29 %, but this difference was not statistically significant (4.7 ± 0.5 mm vs. 6.6 ± 0.8 mm, $p = 0.0575$).

4. Discussion

With the continuous increase of patients in the geriatric and

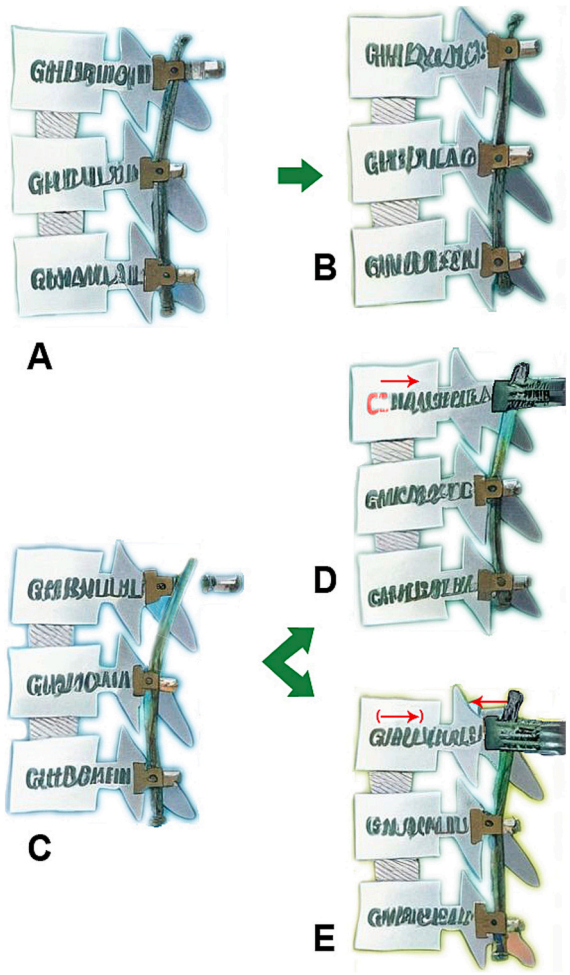

Fig. 5. Schematic illustration of the vertebrae–implant construct in both groups, before and after rod persuading. **(A)** Schematic representation of the non-RP group. The rod has already been fixed with set screws in the screw heads at L4 and L5, thereby eliminating the polyaxial motion. The rod fits passively into the screw head at L3, allowing the set screw to be inserted without tension. **(B)** The set screw is inserted into the screw head without applying additional force or load to the pedicle screw. **(C)** Schematic representation of the RP group. The rod has already been fixed in the screw heads at L4 and L5. However, it stands 5 mm above the implanted pedicle screw at L3, and the set screw cannot be secured as the thread does not engage. To insert the set screw, a RP is used, pulling the screw upward to bring the rod into the screw head. This creates additional mechanical load in the screw–rod construct. **(D)** Schematic illustration of RP use. If the pedicle screw's pullout strength is lower than the force required to deform the semi-elastic titanium rod, an immediate, macroscopically visible screw pullout may occur. This is less commonly observed at the cranial screw. **(E)** The use of the RP bends the titanium rod, creating axial tensile force on the pedicle screw. This may result in a screw loosening that is not macroscopically visible. As a consequence, the screw's pullout strength is reduced by an average of 31 %, and this effect is particularly pronounced in osteoporotic bone.

multimorbid patient population undergoing spinal surgery, the prevention of avoidable adverse events leading to revision surgeries is critical (Lang et al., 2023). Screw loosening remains one of the most significant causes of invasive revisions in lumbar spinal fusion procedures (Rometsch et al., 2020). Our study indicates that the use of the RP significantly reduces primary pedicle screw stability, as measured by pullout strength, particularly in osteoporotic vertebral bodies. Although the RP also decreases anchoring stability in non-osteoporotic vertebral bodies, this effect is notably less pronounced.

Several biomechanical considerations support the findings of our study. First, the use of the RP creates axial tension on the rigid pedicle screw, drawing the screw head toward the rod. This enables the correction of a vertebral slip toward the dorsal side through bilateral traction or the derotation of a vertebral body as part of a rotational-slip process, as typically performed in the surgical treatment of adolescent idiopathic scoliosis (AIS) or degenerative lumbar scoliosis. However, our results show that as bone quality decreases, there is an initial reduction in primary screw stability, averaging 31 %. This seems to be primarily due to a minimal axial pullout of the pedicle screw toward the dorsal side, as evidenced by a 29 % average reduction in the distance to measurable pullout compared to the group without RP use. The use of the RP generally led to a reduction in pull-out strength, both in healthy and osteoporotic bone. Interestingly, the pull-out strength of screws in healthy bone tissue treated with the RP was even slightly lower than that of screws in untreated osteoporotic bone. This suggests that the use of the RP reduces the anchorage of pedicle screws in normal bone to a level comparable to that in osteoporotic bone. However, the screws used in this study feature a double thread in the proximal section, which provides increased anchorage in the pedicle region compared to standard pedicle screws. Combined with the conical screw design, this may enhance screw engagement, particularly in osteoporotic bone. As shown in the literature, the weakest point of screw fixation is typically the cancellous bone of the vertebral body, especially in osteoporotic conditions (Cho et al., 2010; Schomig et al., 2023). Therefore, the double-thread design aims to improve fixation in the cortical bone of the pedicle section to reduce the risk of pull-out. It must be assumed that axial pull-out occurs once the screw loses fixation in the pedicle, as the cancellous bone alone cannot resist these forces. Nevertheless, strong engagement in the vertebral body's cancellous bone can contribute to overall pull-out strength and enhance primary stability (Eysel et al., 1998). The most pronounced reduction in pull-out strength was observed when the RP was applied in osteoporotic bone. It is likely that the single application of the RP leads to increased stress on the cortical bone of the pedicle, particularly in osteoporotic bone, which cannot be compensated by the reduced cancellous bone quality in the vertebral body. This results in a substantial loss of primary stability. Accordingly, our findings suggest that the poorer the bone quality, the more pronounced is the negative impact of the persuader on screw stability.

According to our study design, we performed a three-level spondylodesis and investigated the use of a RP to connect the set screws at the cranial vertebra of the construct (L3). The cranial end represents a critical region of the fusion construct, as it is particularly susceptible to the development of adjacent segment instability. Moreover, pedicle screw pullout at this location can potentially compromise the integrity of the entire intervertebral fusion construct. In our setup, the rod was already securely fixed to the fourth and fifth lumbar vertebrae via the set screws, thereby eliminating the polyaxiality of the pedicle screw heads. As a result, our findings may, in principle, be extrapolated to longer constructs. This includes, for example, fusion constructs extending from the ilium to L3 or constructs terminating at vertebrae with comparable morphological characteristics (such as T12 to L4). In clinical practice, however, there are also common scenarios where the rod persuader is not used at an end vertebra but rather in the middle of a pedicle-screw rod construct. This is particularly relevant in long-segment fusions, to adapt the rod in cases of reconstructed lumbar lordosis, following corrective osteotomies, or during three-dimensional spinal realignment procedures in deformity surgery. While our study examined the use of the RP at the cranial end of the construct in the lumbar spine and found a 31 % reduction of pedicle screw fixation, Paik et al. observed an average 48 % reduction in pullout strength after using the RP in the middle segment of instrumented thoracic specimens (Paik et al., 2013). Furthermore, in contrast to our study, the authors found a visible screw failure in nearly half of the pedicle screws tested. In a similar experimental setup, Kang et al. even found a 73 % reduction in pullout strength following RP use at the mid-level of the rod after Ponte osteotomies (Kang et al., 2015). These findings suggest that it is not merely the use of

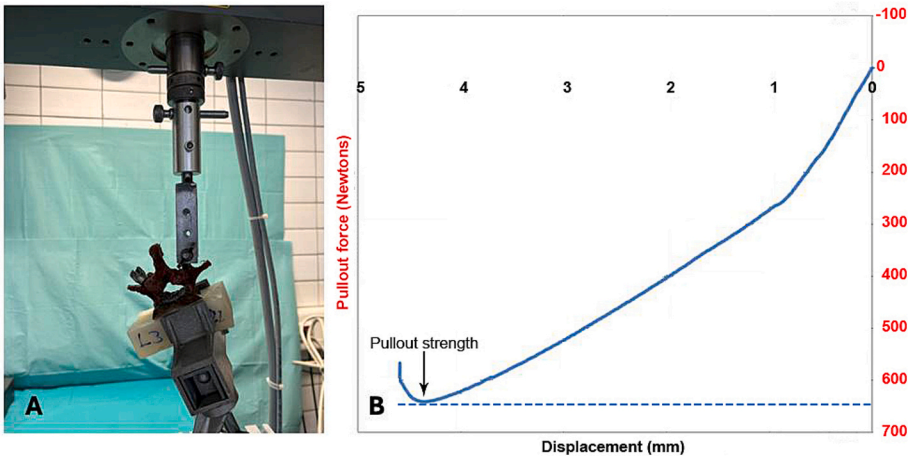

Fig. 6. **(A)** Experimental setup of the specimen secured in the testing machine (Zwick/Roell). The L3 vertebral body is embedded in PMMA, allowing strict axial tensile loading until failure. **(B)** Example of a pullout force/displacement curve from the experiment: the y-axis represents the corresponding pullout force in Newton [N], and the x-axis represents screw displacement in millimeter [mm]. The tensile load was applied at a rate of 0.25 mm per s. * denotes the sudden loss of resistance (>5 %), defined as complete screw pullout and the end of the test.

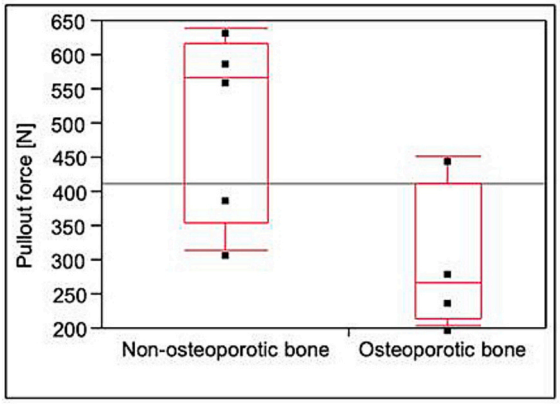

Fig. 7. Box-plot diagram of the force required for screw pullout after the use of the persuader. A significant difference is observed between osteoporotic and non-osteoporotic bone.

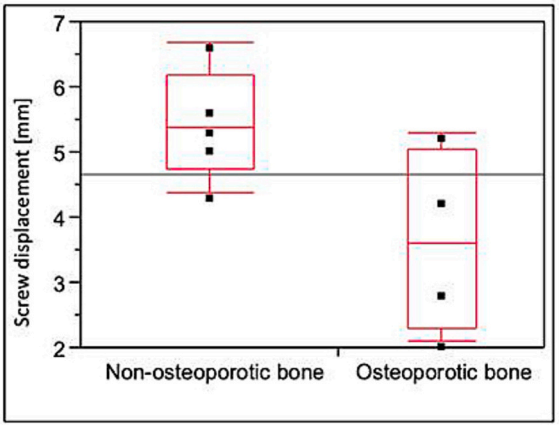

Fig. 8. Box-plot diagram of screw displacement until complete loss of resistance after the use of the persuader. A significant difference is observed between osteoporotic and non-osteoporotic bone.

Table 1
Pullout force (in N ± 1SEM).

	Pullout force [N]		p-value
	Group 1	Group 2	
All specimen (n = 9)	412 ± 54	599 ± 78	0.0671
Osteoporotic specimen (n = 4)	298 ± 55	579 ± 164	0.1555
Non-osteoporotic specimen (n = 5)	503 ± 63	614 ± 76	0.2926
p-value	0.0483*	0.8424	

* significant difference in between groups.

Table 2
Displacement during pullout (in mm ±1SEM).

	Displacement during pullout [mm]		p-value
	Group 1	Group 2	
All specimen (n = 9)	4.7 ± 0.5	6.6 ± 0.8	0.0575
Osteoporotic specimen (n = 4)	3.7 ± 0.7	5.7 ± 1.6	0.2936
Non-osteoporotic specimen (n = 5)	5.5 ± 0.4	7.4 ± 0.8	0.0633
p-value	0.0486*	0.3413	

* significant difference in between groups.

the RP itself but particularly how it is applied that significantly impacts construct stability. Besides osteoporosis as a significant factor for a reduced anchoring stability of the pedicle screws, the use of the RP in middle segments of the instrumented vertebra appears to weaken the construct more than its use at the cranial end. Furthermore, the RP seems to have a less detrimental effect when the mobility of the segment being corrected is greater.In addition to the immediate loss of stability due to axial tension on the rigid pedicle screw, Kernich et al. used strain gauges to measure the bending of the titanium rod after it was adapted to the pedicle screw, both with and without the use of an RP (Kernich et al., 2024). Over the subsequent 30 min, the rod gradually returned to its original curvature. This bending was not observed without the use of the RP. This suggests that the use of the RP and the resulting rod bending create a restorative force that continuously exerts axial tension on the screw after the rod is connected to the pedicle screw. Given that no force is lost in a closed system, the rebending of the rod can be attributed to either the further repositioning of the vertebral body or a gradual pedicle screw pullout with minimal screw displacement. Overall, the findings of our study strongly indicate that rod persuading should be performed only when necessary. While using the RP is indispensable in deformity surgery, particularly in cases such as three-dimensional correction in AIS with good bone quality, it should be strictly avoided when the purpose is to circumvent the need for external bending of a non-precisely contoured rod. According to our data, this is especially

crucial for patients with osteoporosis. If rod persuading is unavoidable in cases of reduced bone quality, such as during the treatment of degenerative lumbar scoliosis or high-grade spondylolisthesis, consideration should be given to cementing the pedicle screws prior to reduction (Boucas et al., 2023; Heck et al., 2024; Rometsch et al., 2020).

However, our study has some limitations. One limitation is the small number of specimens tested. Our results suggest that with a larger sample size, significant differences would likely emerge not only in the osteoporotic specimens with RP use but also in the non-osteoporotic specimens. Nevertheless, despite the small sample size, the significant reduction in pullout strength in osteoporotic vertebral bodies highlights how carefully patients with reduced bone quality should be treated. Another limitation is that only one type of pedicle screw was investigated. The screws used are the standard implants in our institution, which is why they were selected for this study. More pronounced effects might be observed with single-threaded screws featuring a coarse and cylindrical design, particularly in relation to pull-out and loosening in intervertebral fusion procedures (Liu et al., 2020; Shea et al., 2014). In this context, future studies should investigate the extent to which different screw or cage designs influence screw pull-out strength after RP use - with and without cement augmentation. Furthermore, while rod persuading exerts significant tension on the pedicle screw, our study does not provide data on whether the use of a Rod Pusher might result in a less pronounced reduction in pedicle pullout force in osteoporotic bone. A comparison of our biomechanical results with clinical data would have been of interest; however, published evidence on the clinical application of the RP remains scarce. Lastly, due to the nature of our experimental setup using specimens from body donors, we did not perform Dual-Energy X-ray Absorptiometry (DEXA) measurements to determine the T-score, which remains the gold standard for diagnosing osteoporosis (Kanis et al., 1994; Roux and Briot, 2017). Instead, we used HU to define osteoporosis (Scheyerer et al., 2019). However, recent studies suggest that, with respect to the incidence of screw loosening, the vertebra-specific bone density assessment using HU measurements does not appear to be inferior to DEXA (Schreiber et al., 2011; Zou et al., 2020b).

5. Conclusion

In lumbar spinal fusion procedures, the use of the RP reduces the pedicle screw pullout strength, thereby compromising the construct stability. This reduction of primary pedicle screw fixation strength is particularly significant in osteoporotic vertebral bodies, highlighting the need for careful consideration of RP use in this patient population. While the RP remains indispensable for deformity corrections, its routine application should be avoided when alternative methods, such as precise rod contouring, are feasible. For cases where rod persuading is unavoidable in patients with poor bone quality, preoperative strategies such as screw cementation should be strongly considered to reduce the risk of implant-related complications.

CRediT authorship contribution statement

Vincent J. Heck: Writing – original draft, Resources, Methodology, Investigation, Data curation, Conceptualization. **Tobias Prasse:** Writing – original draft, Resources, Methodology, Investigation, Data curation, Conceptualization. **Juan Manuel Vinas-Rios:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andreas Prescher:** Validation, Supervision, Resources. **Lajos Basten:** Methodology, Investigation, Data curation. **Maximilian Weber:** Methodology, Data curation, Conceptualization. **Peer Eysel:** Supervision. **Nikolaus Kernich:** Writing – original draft, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Informed consent

Informed consent was obtained from all individual participants included in the study. The study's protocol was reviewed and approved by the Institutional Review Board (No.23–1417).

Ethical statements

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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