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# Comparison of three sacral screw internal fixation techniques in the treatment of L4–S1 lumbar degenerative disease with osteoporosis: a retrospective observational study

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## Abstract

**Background** Patients with L4–S1 lumbar degenerative disease (LDD) with osteoporosis are prone to sacral-screw loosening during spinal internal fixation. We aimed to compare the clinical efficacy and imaging results of sacral bicortical, tricortical, and polymethylmethacrylate (PMMA)-augmented pedicle-screw fixation in the treatment of L4–S1 LDD with osteoporosis.

**Methods** This is a retrospective study, 72 patients were enrolled and divided into three groups according to the S1-screw fixation method: PMMA-augmented pedicle-screw fixation (Group A,  $n=26$ ), bicortical fixation (Group B,  $n=22$ ), and tricortical fixation (Group C,  $n=24$ ). The visual analog scale (VAS) and Oswestry disability index (ODI) were recorded preoperatively and at the last follow-up, and the postoperative complications, screw-loosening rate, and fusion rate were compared between the three groups.

**Results** Upon the last follow-up, the VAS and ODI scores of the three groups were significantly improved compared with those recorded preoperatively. The VAS and ODI scores of Group A were significantly smaller than those of Groups B and C ( $P < 0.05$ ), with no significant difference between Groups B and C. Moreover, the screw-loosening rate of Group A was significantly lower than that of Groups B and C ( $P < 0.05$ ), with no significant difference between Groups B and C. No significant difference was noted in postoperative complications, bone-cement leakage rates, and intervertebral fusion rates among the three groups. Furthermore, we found that osteoporosis and change of lumbar lordosis (LL) value were independent risk factors for sacral-screw loosening in patients with L4–S1 LDD with osteoporosis.

**Conclusions** When patients with L4–S1 LDD with osteoporosis undergo lumbosacral fusion and fixation, the use of S1 pedicle screws with PMMA augmentation has better stability and less screw loosening. Furthermore, we

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recommend this surgery for patients with osteoporosis, and the LL should be increased as much as possible during the operation to restore the matching of lumbar and pelvic parameters.

**Keywords** Lumbar degenerative disease, Osteoporosis, Sacral screw, Polymethylmethacrylate -augmented

## Background

Lumbar degenerative disease (LDD) is common among middle-aged and older people. These patients often have symptoms that seriously affect their quality of life, including lower back pain, radiating pain to the lower limbs, and intermittent claudication. The groups most susceptible to this disease are middle-aged and older women [1].

Surgical treatment is often required in patients with LDD with neurological damage caused by severe lumbar spinal stenosis, lumbar spondylolisthesis, or lumbar instability if conservative treatment is ineffective [2]. Currently, the most commonly used surgical option is pedicle screw internal fixation. However, older patients often suffer from osteoporosis; therefore, their vertebral trabeculae are sparse and bone fragility increases. Thus, the risk of postoperative screw loosening, screw breakage, and pseudoarthrosis formation also increases [3, 4]. Therefore, the surgical treatment of LDD with osteoporosis has become an interesting topic.

Due to the special anatomical structure and biomechanical characteristics of the sacrum, screw loosening is most common at the sacrum [5]. In recent years, various advanced technologies have been developed to enhance the pull-out resistance of sacral screws in patients with osteoporosis [6, 7]. Currently, bicortical, tricortical, and polymethylmethacrylate (PMMA)-augmented pedicle-screw fixation are commonly used clinically. Although bicortical and tricortical fixation improve the strength of the sacrum-screw interface to a certain extent, there is still a certain rate of screw loosening with the extension of the fixed segment and the occurrence of osteoporosis [5]. In contrast, S1 pedicle screws with PMMA augmentation can increase the screw's pull-out resistance by approximately 81–252% by increasing the contact area between the screw and surrounding bone trabeculae through the bone cement medium [8]. Therefore, due to its simple operation and high fixation strength, the use of S1 pedicle screws with PMMA augmentation is gradually becoming one of the most commonly used methods to enhance the pull-out resistance of screws in osteoporotic vertebrae [9, 10].

Clinically, most cases of LDD are single-segmented, often occurring at the L4/5, while continuous double-segment LDD is rare [11]. Previously, our early studies found no significant difference in clinical effects when the PMMA-augmented pedicle-screw method was used in single-segment LDD with osteoporosis. Therefore, the use of PMMA-augmented technology is not recommended in single-segment LDD [5]. However, there is

currently limited literature on whether the application of S1 pedicle screws with PMMA augmentation can reduce the screw-loosening rate and improve the fusion rate in patients with double-segment LDD with osteoporosis. Therefore, we aimed to conduct a clinical controlled study comparing the use of bicortical fixation, tricortical fixation, and S1 pedicle screws with PMMA augmentation when performing lumbosacral fusion fixation in patients with L4–S1 LDD combined with osteoporosis to explore the clinical efficacy of different sacral fixation methods and their ability to resist screw loosening.

## Methods

### Patient characteristics

This study included 72 patients with L4–S1 LDD with osteoporosis (9 males and 63 females) aged 53–87 years (mean age, 69 years) who underwent transforaminal lumbar interbody fusion (TLIF) between January 2016 and May 2021. The patients were grouped as follows according to the sacrum fixation method used: Group A, S1 pedicle screws with PMMA augmentation group ( $n=26$ ); Group B, S1 bicortical fixation group ( $n=22$ ); and Group C, S1 tricortical fixation group ( $n=24$ ) (Table 1).

All consecutive patients signed a written approval of the operation and were operated on by the same surgeon with extensive experience. This study was reviewed and approved by the appropriate ethics committee (NO. K-2024-046).

### Inclusion and exclusion criteria

The inclusion criteria were as follows: (i) diagnosed with L4–S1 LDD, and both degenerative levels were involved in the patient's symptoms (ii) all had severe lower back pain and/or lower limb pain before surgery, with regular conservative treatment for more than 3 months deemed as ineffective or having poor efficacy; and (iii) dual-energy X-ray absorptiometry determining bone mineral density (BMD) as  $T \leq -2.5$  SD.

The exclusion criteria were as follows: (i) the presence of coexisting fresh vertebral fractures, spinal tumors, or spinal infectious diseases; (ii) previous lumbar internal fixation of the operative segment; (iii) intolerance to surgery; and (iv) loss to follow-up.

### Anti-osteoporosis treatment

All patients received calcium and vitamin D Drops supplements and systemic anti-osteoporosis treatment throughout the treatment period: Vitamin D Drops (400u bid), Calcium Carbonate and Vitamin D<sub>3</sub> Tablets (600 mg

**Table 1** Comparison of base data in three groups

Characteristic	Group A (n = 26)	Group B (n = 22)	Group C (n = 24)	p-value
Age(year)	68.73 ± 6.99	71.41 ± 9.47	68.67 ± 7.44	0.42
Sex (male/female)	3/23	2/20	4/20	0.73
BMD	-3.48 ± 0.41	-3.23 ± 0.41	-3.26 ± 0.47	0.09
BMI	22.35 ± 3.52	21.78 ± 2.78	22.40 ± 2.73	0.75
Follow-up(months)	36.31 ± 9.12	34.73 ± 12.72	39.46 ± 15.97	0.44
Pre-op VAS score	7.27 ± 1.00	7.05 ± 1.05	7.17 ± 1.09	0.76
Pre-op ODI score	51.90 ± 9.64	53.96 ± 5.83	51.08 ± 8.44	0.48

bid), subcutaneous injection of Denosumab Injection (60 mg / every six months).

### Outcome assessment

#### Clinical assessment

To assess the clinical outcomes, we recorded the visual analog scale (VAS) and Oswestry disability index (ODI) scores of the patients before surgery and at the last follow-up. VAS and ODI scores were recorded by ward physicians during outpatient visits or telephone follow-up. The intraoperative time, intraoperative blood loss, and hospitalization time of the three groups of patients were analyzed. Additionally, the incidence rates of complications such as surgical site infection, nerve root injury, and dural sac tear were compared between each group.

#### Radiographic assessment

Lumbar spine X-ray or computed tomography (CT) examination was performed at the last follow-up to record the incidence of screw loosening, intervertebral fusion, and bone cement leakage. Two experienced doctors performed the image measurements through our

hospital's picture archiving and communication systems. Spinopelvic parameters such as lumbar lordosis (LL), pelvic inclination (PI), pelvic tilt (PT), sacral slope (SS), and PI-LL were measured before surgery and at the last follow-up.

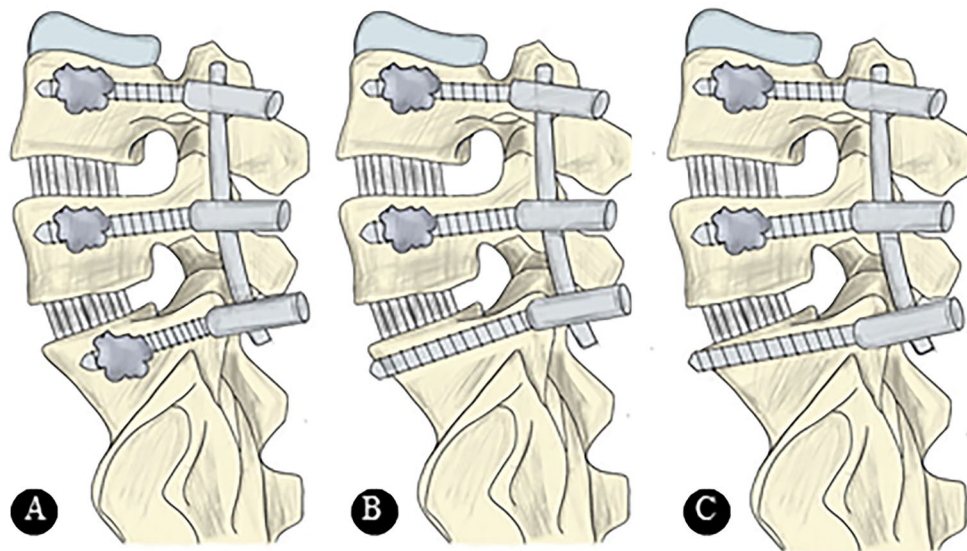
Screw loosening was defined as a halo sign of >1 mm around the screw visible upon postoperative X-ray or CT [12]. Moreover, intervertebral fusion was defined as visible bone tissue growth in or around the fusion cage upon postoperative X-ray or CT and the formation of a continuous cancellous bone bridge between the vertebral bodies of the fused segments [13]. Furthermore, the bone leakage rate was calculated as follows: bone cement leakage rate = (number of leaking screws/total number of reinforced screws) × 100%.

#### Surgical methods

All patients underwent L4–S1 TLIF. Experienced surgeons decide whether to use PMMA-augmented technology based on the patient's preoperative BMD and the mechanical strength of the screw during intraoperative screw placement. The initial incision was made along the posterior median approach, after which the lateral part of the “herringbone ridge” was exposed in sequence for needle insertion into the pedicle (Fig. 1).

#### S1 pedicle screws with PMMA augmentation group

Under fluoroscopy, hollow pedicle screws (REACH Medical, Shanghai, China) were inserted into the lumbar pedicle and bone cement was injected through these for reinforcement. The puncture tube (Medtronic, Minneapolis, Minnesota, USA) was then inserted through the sacral pedicle to inject bone cement (TECRES

**Fig. 1** Schematic diagram. (A): S1 pedicle screws with PMMA augmentation. (B): Bicortical fixation. (C): Tricortical fixation

S.P.A, Sommacampagna, Italy). Bone cement injection was stopped when it was close to the posterior edge of the vertebral body. Each injection of bone cement was approximately 0.1 ml, and single-screw injection inserted approximately 2.0 mL of bone cement into the duct. Next, the cement application system was pulled out, and solid pedicle screws (REACH Medical) were inserted quickly. Next, the transforaminal lumbar interbody fusion was completed. A polyether ether ketone interbody cage (Guona Science and Technology, Sichuan, China) and autogenous and allogeneic bones were used.

**Bicortical and tricortical fixation groups**

The surgical procedures for bicortical and tricortical fixations were principally the same as that for S1 pedicle screws with PMMA augmentation; however, these two procedures only used pedicle screws with PMMA augmentation on the lumbar spine, while simple solid pedicle screw fixation was used on the sacrum. The bicortical screw was placed at a 25°-angle between the upper endplate of S1 and the sagittal plane, penetrating the vertebral body, with the tip of the screw penetrating the anterior bone cortex. In contrast, the tricortical screw was placed at a 25°-angle between the sacral promontory and the sagittal plane, with the tip of the screw penetrating the cortex of the sacral promontory.

**Statistical analysis**

All data were analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Continuous data are expressed as means±standard deviations, while categorical variables are expressed as numbers and percentages. The data that met the normal distribution and variance homogeneity between the two groups were compared by t-test, and the data that did not meet the normal distribution or variance heterogeneity were compared by nonparametric rank sum test. The data that met the normal distribution among multiple groups were compared by 1-way ANOVA, and the data that did not meet the

normal distribution were compared by Kruskal-Wallis test. The chi-square test was used to compare categorical variables.

**Risk factor analysis:** After univariate analysis, the variables with statistically significant differences were included in the binary logistic regression analysis. Multivariate logistic regression analysis was used to determine the independent risk factors for screw loosening after double-segment fixation. *P*<0.05 was considered statistically significant.

**Partial correlation analysis:** After controlling for BMD, partial correlation analysis was used to analyze the correlation between S1 fixation method and screw loosening.

**Results**

**Baseline data**

Notably, no statistical difference was observed between the three groups of patients in terms of age, sex, BMD, body mass index (BMI), follow-up time, preoperative VAS, and ODI (*P*>0.05). These variables were comparable between the three groups.

**Clinical outcomes**

Postoperative follow-up was done at 24–72 months. At the last follow-up, the VAS and ODI scores of Group A were significantly smaller than those of Groups B and C (all *P*<0.05); however, no significant difference was observed in the VAS and ODI scores of Groups B and C (*P*>0.05). Additionally, no statistical difference was noted in the operation time, intraoperative blood loss, and hospitalization time between the three groups (all *P*>0.05). (Table 2).

**Radiological outcomes**

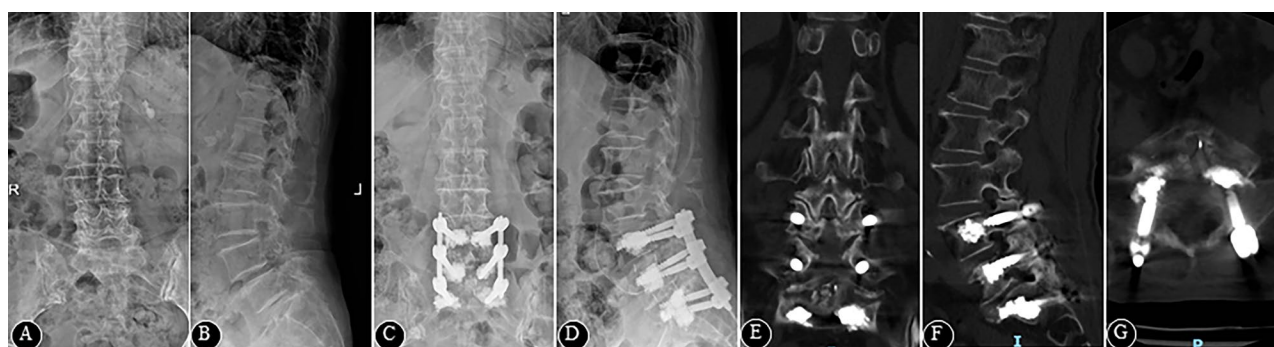
**Comparison of the bone-cement leakage rates**

In Group A, the average bone-cement injection volume per screw was 2.04±0.63 ml and the lumbar bone-cement leakage rate was 18.27% (19 screws). Moreover, the average bone-cement injection volume per screw in

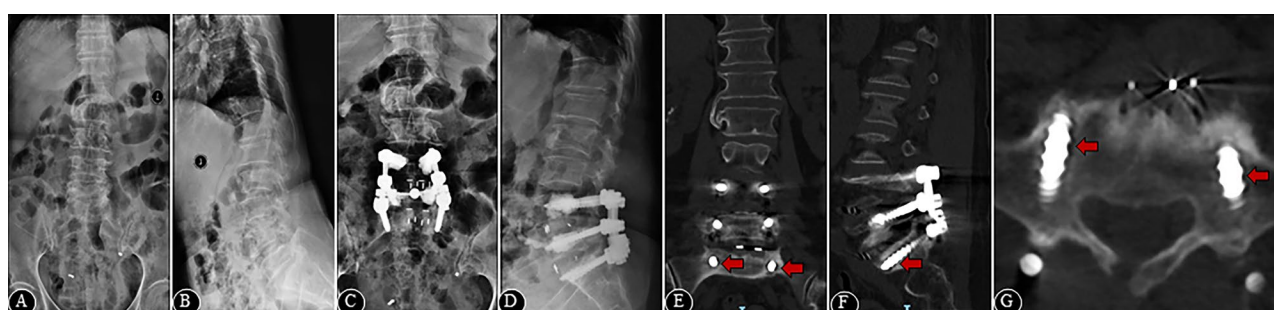
**Table 2** Comparison of clinical effects and complications among three groups

Characteristic	Group A(n=26)	Group B(n=22)	Group C(n=24)	P value		
				A vs. B	A vs. C	B vs. C
Operation time(min)	267.88±62.42	241.50±47.75	277.29±73.43	0.11	0.85	0.19
Intraoperative blood loss(mL)	409.23±189.14	513.64±364.66	455.00±340.83	0.73	0.87	0.67
Hospital stay(day)	13.58±7.13	15.82±6.43	15.66±4.76	0.12	0.06	0.72
Screw loosening (n)	0	4	4	0.08		
Complications (n)	2	2	3	0.85		
Fusion rate (n)	26	21	23	0.54		
Cement leakage (n)	29/156	16/88	17/96	0.99		
VAS at last follow-up	2.23±0.76*	2.95±1.05*	2.96±1.00*	0.01	0.01	0.95
ODI at last follow-up	17.77±7.99*	22.55±5.76*	22.00±5.36*	0.02	0.02	0.74

\*Significantly greater than the value found in preoperatively



**Fig. 2** Male patient, 66 years old,  $T = -4.1$  SD, S1 pedicle screws with PMMA augmentation. (A) – (B): Preoperative X-ray. (C) – (D): Postoperative X-ray. (E) – (G): Postoperative CT showed good intervertebral fusion and no screw loosening



**Fig. 3** Female patient, 64 years old,  $T = -3.4$  SD, bicortical fixation. (A) – (B): Preoperative X-ray. (C) – (D): Postoperative X-ray. (E) – (G): Postoperative CT showed halo sign has appeared around the S1 screws (red arrows), and the S1 pedicle screw has loosened

S1 was  $1.76 \pm 0.59$  mL, with a bone-cement leakage rate of 19.23% (10 screws). The total bone-cement leakage rate was 18.59%. In Group B, the average bone-cement injection volume per screw was  $1.50 \pm 0.46$  mL, and the lumbar bone-cement leakage rate was 18.19% (16 screws). Similarly, the average bone-cement injection volume per screw in Group C was  $1.77 \pm 0.47$  mL, with a lumbar spine bone-cement leakage rate of 17.71% (17 screws). There was no statistically significant difference in the bone-cement leakage rates between the three groups ( $P > 0.05$ ).

S1 bone-cement leakage was caused by the screw penetrating the anterior bone cortex. Notably, we observed no serious complications such as nerve damage or pulmonary embolism caused by bone-cement leakage.

#### **Comparison of the screw-loosening and interbody fusion rates**

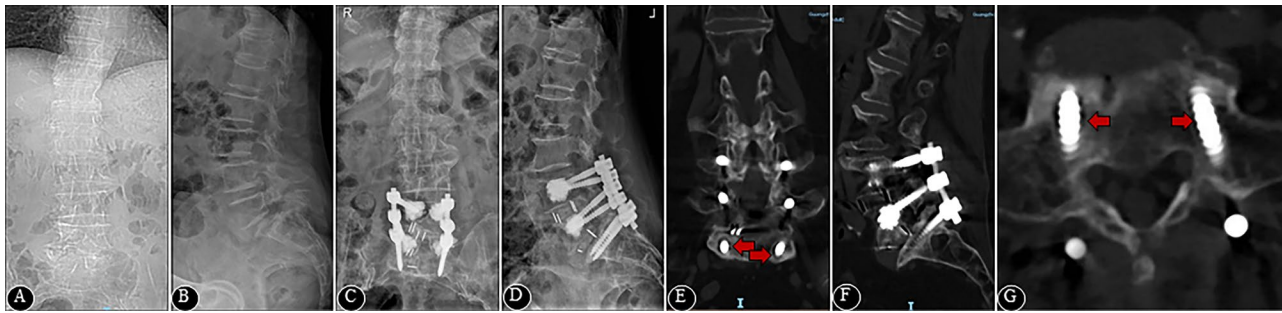
No screw loosening or breakage occurred in any of the 26 patients in Group A, and all surgical segments achieved bony fusion at the last follow-up (Fig. 2). In contrast, four patients in Group B showed S1 screw loosening (25.93%), of which one patient had L5–S1 non-fusion (Underwent revision surgery at an external hospital) and three patients had L5/S1 fusion (three patients did not undergo revision surgery) (Fig. 3). Similarly, four patients in Group C had S1 screw loosening (25.81%), of which one patient had L5–S1 non-fusion, one patient

underwent revision surgery in our hospital 1 year later due to adjacent segment degeneration, and two patients had L5/S1 fusion (three patients did not undergo revision surgery) (Fig. 4). Group A had the lowest screw loosening rate and the highest intervertebral fusion rate, but there was no statistically significant difference between groups ( $P > 0.05$ ).

#### **Comparison of the screw-loosening and non-loosening groups**

Patients in Groups B and C were further divided into a loosened screw group and a non-loosened screw group based on S1 screw loosening. Upon comparison of age, sex, BMI, BMD, and spine-pelvic sagittal parameters between these groups, we found that the two groups had statistically significant differences in BMD, postoperative PI–LL and Change of LL. However, no significant differences were noted in age; sex; BMI; preoperative and postoperative LL, SS, PT, and PI; and preoperative PI–LL ( $P > 0.05$ , Table 3).

BMD, postoperative PI–LL and Change of LL were included in binary logistic regression analysis. The results showed that BMD and Change of LL were independent risk factors for screw loosening after L4–S1 internal fixation ( $P < 0.05$ , Table 4).



**Fig. 4** Female patient, 73 years old, T= -2.9 SD, tricortical fixation. (A) – (B): Preoperative X-ray. (C) – (D): Postoperative X-ray. (E) – (G): Postoperative CT showed halo sign has appeared around the S1 screws (red arrows), and the S1 pedicle screw has loosened

**Table 3** Univariate analysis of risk factor for screw loosening

Variable	Loosening group	Non-loosening group	Statistical value	P value
Age(year)	72.38±8.48	69.47±8.52	t=0.876	0.39
Sex (male/female)	1/7	5/33		1.00
			$\chi^2=0.000$	
BMD	-3.53±0.44	-3.19±0.42	z=-2.085	0.03
BMI	23.38±2.87	21.83±2.67	t=1.463	0.15
Operation (bicortical/tricortical)	4/4	18/20	$\chi^2=0.000$	1.00
LL (°)				
Pre-operation	35.62±4.87	35.73±15.03	t=-0.20	0.98
Post-operation	38.30±4.49	39.94±14.91	t=-0.569	0.57
Change of LL	2.68±0.63	4.21±0.93	t=-4.463	<0.001
SS (°)				
Pre-operation	37.60±13.84	33.36±3.79	t=0.880	0.38
Post-operation	36.11±8.89	36.06±10.96	t=0.015	0.99
PT (°)				
Pre-operation	16.32±6.52	20.60±3.79	t=-1.791	0.11
Post-operation	20.20±8.65	17.45±4.46	z=-0.493	0.62
PI (°)				
Pre-operation	59.33±3.69	56.58±9.85	t=1.331	0.19
Post-operation	60.80±3.81	55.90±9.59	t=1.411	0.17
PI-LL (°)				
Pre-operation	23.71±6.05	20.86±13.76	t=0.570	0.57
Post-operation	22.50±5.72	15.96±13.29	t=2.214	0.04

**Table 4** Multivariate logistic regression analysis results for the loosening group

Factor	OR(95% CI)	P value
BMD	6.625(1.062,41.336)	0.043
Post-operation PI-LL	0.952(0.886,1.024)	0.184
Change of LL	14.984(2.362, 95.074)	0.004

#### Correlation analysis between sacral 1 fixation methods and screw loosening

In order to more scientifically reflect the correlation between S1 fixation method and screw loosening, partial correlation analysis was used to analyze the correlation between S1 fixation method and screw loosening after controlling BMD factors. The results showed that S1 fixation method was correlated with screw loosening ( $r=0.281$ ,  $P=0.018$ ).

#### Complications

The following complications were observed in Group A: (i) one patient developed numbness of the contralateral lower limb after surgery, which improved after 2 weeks of symptomatic treatment such as neurotrophic treatment, and the patient did not complain of discomfort at the last follow-up; and (ii) one patient suffered a dural sac tear, which was repaired during the operation and improved after postoperative symptomatic treatment.

The following complications were observed in Group B: (i) two patients experienced worsening numbness in the lower limbs on the affected side, of which one patient improved after 10 d of symptomatic treatment and one patient still complained of numbness in the lower limbs at the 2-year follow-up; however, the symptoms were mild.

The following complications were observed in Group C: (i) one patient suffered a dural sac tear, which was repaired during the operation and improved after postoperative symptomatic treatment; (ii) one patient had decreased muscle strength in both lower limbs after surgery, which improved after 1 week, and the patient did not complain of discomfort at the last follow-up; (iii) one patient developed numbness of the contralateral lower limb after surgery, which improved after 2 weeks of symptomatic treatment such as neurotrophic treatment, and the patient did not complain of discomfort at the last follow-up.

#### Discussion

Biomechanical studies have shown that the local stress at the lumbar-sacral transition is relatively concentrated, the sacral pedicle is wide in diameter and short in length, and the sacral cortical bone is weak [14]. After surgical fixation for LDD, the reduction of movable vertebral bodies causes the head and tail screws to bear the increased load. Additionally, when in combination with osteoporosis, the risk of screw loosening in the sacrum is higher, with an incidence rate of 15.6–46.5% [15]. Therefore, obtaining adequate sacral fixation is an important and

challenging clinical issue when patients with LDD combined with osteoporosis require sacral fixation.

Currently, sacral bicortical and tricortical pedicle screws are widely used to improve the fixation strength of sacral screws. Bicortical screws increase the holding power of the anterior cortex of the sacrum, while tricortical screws increase the anchoring of the bony dense area of the upper endplate on the basis of bicortical screws. However, some studies have shown that with the extension of the fixed segment and the occurrence of osteoporosis, a certain rate of bicortical and tricortical pedicle screw-loosening remains [14]. Additionally, because the anterior of the sacrum is close to the main neurovascular structures, bicortical and tricortical pedicle screws have the potential risk of damaging the nerves and blood vessels anterior to the sacral spine [16]. Currently, S1 pedicle screws use PMMA augmentation to increase the contact area between the screw and surrounding bone trabeculae, increasing the screw's pull-out resistance. In fact, biomechanics shows that its pull-out resistance is nearly five times higher than that of ordinary pedicle screws. Furthermore, these screws can provide an immediate stabilizing effect; therefore, this has become one of the most commonly used surgical methods [9, 10].

Previously, Ngu et al. [17] compared the pull-out resistance of S1 expansion screws and bone cement-reinforced screws and found that the pull-out resistance of bone cement-reinforced screws was better than that of expansion screws. Moreover, Zhuang et al. [18] compared the biomechanical strength of bicortical fixation and monocortical bone cement-enhanced fixation using cadaveric sacrum specimens. They found that bone cement-enhanced fixation provided better fixation strength. Furthermore, the use of pedicle screws with PMMA augmentation has been shown to effectively reduce the occurrence of internal fixation complications in clinical practice. However, the research subjects of existing studies are often single-segment or mixed single-segment and multi-segment patients [5, 19], and few clinical reports on the application of sacral pedicle screws with PMMA augmentation in double-LDD with osteoporosis exist.

The present study compared the clinical efficacy of bicortical fixation, tricortical fixation, and S1 pedicle screws with PMMA augmentation in the treatment of L4–S1 LDD with osteoporosis. The results showed that none of the 26 patients who underwent fixation using S1 pedicle screws with PMMA augmentation had sacral screw loosening, and all achieved good intervertebral fusion. In contrast, four patients in each of the bicortical and tricortical fixation groups showed S1 screw loosening and decreased intervertebral fusion. Moreover, at the last follow-up, the VAS and ODI scores were significantly higher in the bicortical and tricortical fixation

groups than those in the S1 pedicle screws with PMMA augmentation group ( $P < 0.05$ ). By evaluating the cases of intervertebral fusion failure, we propose that the loosening of the S1 screw partially contributed to the decreased intervertebral fusion rate, with other causes being that the upper and lower endplates of the bone grafting site were not cleaned and the bone grafting was insufficient.

Furthermore, through the comparison of age, sex, BMD, and spinopelvic parameters between the screw-loosening and non-screw-loosening groups, we found that the two groups had statistically significant differences in BMD, postoperative PI–LL and Change of LL. Binary logistic regression analysis showed that BMD and Change of LL were independent risk factors for screw loosening after L4–S1 internal fixation. Therefore, we recommend that: (i) it is critical to complete a preoperative BMD examination. Since our study found that patients with BMD T value  $\leq -3.5$  SD have an increased probability of screw loosening, we propose that using S1 pedicle screws with PMMA augmentation is a better surgical option for patients with low BMD; (ii) the spinopelvic parameters should be fully considered preoperatively. It is necessary to increase the LL to the greatest possible extent intraoperatively to restore the matching of the lumbar spine and pelvic parameters. Simultaneously, the characteristics of osteoporosis in older patients should be taken into account, and it is not recommended to force or overcorrect in these patients; (iii) Since PMMA-augmented pedicle-screws are used in both L4 and L5, the local stress of S1 pedicle-screw is enhanced, which increases the risk of screw loosening. The use of PMMA-augmented S1 screw can balance the strength of anchors and is therefore a better choice. (iv) Furthermore, close attention should be paid to controlling the patient's activity level, active antiosteoporosis treatment, and follow-up conditions.

Previous studies have reported the incidence of cement leakage with PMMA augmentation pedicle screws to be approximately 38.3–93.6%. Therefore, the bone-cement leakage rate found in this study was lower than that reported in previous studies. In our previous research, we found that the use of small doses (1.5–2.5 ml) of bone cement slowly injected into a single nail channel under fluoroscopy can reduce the bone-cement leakage rate. This leakage rate is also related to the surgeon's proficiency; therefore, we recommend that less experienced surgeons be guided by a senior physician during the operation to avoid the leakage of bone cement into the spinal canal, which may cause severe complications.

### Limitations

The present study had some limitations. First, this was a single-center retrospective study with a small number of included cases and a short follow-up period. Further

prospective randomized controlled studies are needed to confirm the clinical efficacy of this technology. Second, although all operations were performed by the same surgeon, due to the long time span, experience at different stages might have had different effects on the results, which may lead to bias in the clinical results. Finally, due to limited conditions, no biomechanical studies have been conducted to compare the mechanical strength of bicortical, tricortical, and PMMA-augmented pedicle-screw fixation, which will be our future research direction.

## Conclusions

The present study showed that when patients with L4–S1 LDD combined with osteoporosis undergo lumbosacral fusion and fixation, S1 pedicle screws with PMMA augmentation has better stability and less screw loosening. This surgery is recommended for patients with osteoporosis, and the LL should be increased as much as possible during the operation to restore the matching of lumbar and pelvic parameters. Additionally, these patients should actively prevent the occurrence of screw loosening after surgery and receive systematic antiosteoporosis treatment.

## Abbreviations

BMD	Bone mineral density
BMI	Body mass index
CT	Computed tomography
LL	Lumbar lordosis
LDD	Lumbar degenerative disease
ODI	Oswestry Disability Index
PMMA	Polymethylmethacrylate
PT	Pelvic tilt
PI	Pelvic inclination
SS	Sacral slope
TLIF	Transforaminal lumbar interbody fusion
VAS	Visual Analog Scale

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## Author contributions

Conception and design of study, GN Gu, T Liu and YC Tang; Acquisition of data, GN Gu, T Liu, J Ding; Data analysis and / or interpretation, GN Gu, J Ding, YX Li and K Yuan; Drafting of manuscript and/or critical revision, GN Gu, T Liu, HZ Guo and GY Mo; Approval of final version of manuscript, YC Tang, ZD Yang and SC Zhang; Project Administration, YC Tang, SC Zhang, K Yuan, YX Li and GY Mo. All authors read and approved the final manuscript.

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## Data availability

No datasets were generated or analysed during the current study.

## Declarations

### Ethics approval and informed consent

This study has been reviewed and approved by the appropriate ethics committee of The First Affiliated Hospital of Guangzhou University of Chinese Medicine (NO. K–2024–046).

### Consent for publication

All authors read and approved the final manuscript.

### Competing interests

The authors declare no competing interests.

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