Comparison of Percutaneous Cortical Bone Trajectory Screw Fixation Vs. Traditional Percutaneous Pedicle Screw Fixation for Traumatic Type a Lumbar Fractures Without Neurological Deficits

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Research Article

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Abstract

Objective: The purposes of this study were to examine the clinical and radiological outcomes after percutaneous cortical bone trajectory screw fixation (PCBT) for traumatic type A lumbar fractures without neurological deficits and to compare these outcomes with those after traditional percutaneous pedicle screw fixation (PPSF) technique.

Methods: The study included 22 consecutively treated patients who underwent PCBT technique (PCBT group) and a historical control group of 24 consecutively treated patients who underwent traditional PPSF surgery (PPSF group). Clinical outcomes (including Visual analogue scores (VAS), Oswestry disability index (ODI) scores) and radiographic assessments including Vertebral wedge angle (VWA) and Sagittal index were recorded and compared between the two groups.

Results: Incision length and hospital stay in the PCBT group were significantly better than the PPSF group ($p < 0.05$). There were no significant differences between the two groups in clinical and radiographic outcomes, including blood loss, X-ray exposure, surgery time, VAS, ODI scores, VWA and sagittal index ($p > 0.05$ each). However, after multiply adjustment, PCBT group had better postoperative restoration in terms of VWA than the PPSF group ($p < 0.05$).

Conclusions: The present study showed that PCBT is a safe and feasible method for the treatment of lumbar fractures without neurological deficits. It resulted in smaller incisions and shorter period of hospital stay, yet yielded equivalent or superior clinical and radiographic outcomes compared to the traditional PPSF.

Introduction

Thoracolumbar and lumbar fracture accounts for nearly 60% of all traumatic spinal fractures and compression fractures type A (according to the AO classification (Magerl et al. 1994)) is the most common type of fractures (54.8%)(Leucht et al. 2009). Currently, percutaneous pedicle screw fixation (PPSF) was strongly recommended for the treatment of thoracolumbar and lumbar fracture, as it is not only more minimally invasive, but could yield comparable repositioning clinical outcomes compared with open internal fixation(Kocis et al. 2020; Yang et al. 2020; Kreinest et al. 2019). However, some clinical studies have shown rising concerns that this approach was associated with a series of complications during or after surgery, including screw loosening, pedicle screw misplacement, neurological injury, cerebrospinal fluid leakage and abdominal artery injury (Ouchida et al. 2020; Zhao et al. 2018). As to screw loosening, the rate was reported to exceed more than 60% in the patients with osteoporosis(Delgado-Fernandez et al. 2017). Moreover, this technique would unavoidably lead to four separated incisions, which may cause some kind of appearance issues.

Recently, cortical bone trajectory (CBT) technique had been developed by Santoni et al. (Santoni et al. 2009) to increase screw-bone purchase during posterior pedicle fixation. This technique demonstrated higher or equivalent biomechanical properties comparing with the traditional pedicle screw trajectory in the following studies (Matsukawa et al. 2014a; Matsukawa et al. 2013; Matsukawa et al. 2017; Mai et al. 2016). Therefore, it was conceived as an alternative method to traditional pedicle screw fixation, particularly for stabilization of lower lumbar segments with definitive osteoporosis (Sansur et al. 2016). This technique may be a possible solution for reducing the high rate of screw loosening occurred in osteoporotic spinal fractures, but until so far, the long-term outcomes of large-scaled clinical experiments are still lacking.

As the starting point for the CBT screws is at the lateral aspect of the pars interarticularis, they are then implanted with medial to lateral angulation, which is opposite to pedicle screw fixation. This special trajectory allows the whole procedure of screw implantation to be conducted apart from nerve roots, dural sac and anterior vascular structures. Due to this, this approach was considered as a safer technique compared to traditional pedicle screw fixation and may significantly decrease the risk of neurovascular injury (Phan et al. 2015). In addition, this medial-to-lateral insertion pathway made it feasible that percutaneous CBT screw fixation (PCBT) could be conducted percutaneously by only two minimal midline incisions. However, based on our knowledge this minimally invasive technique has not yet been reported for the treatment of spinal fractures. The aims of this study were therefore to examine the clinical and radiological outcomes after percutaneous CBT screw fixation for traumatic type A lumbar fractures and to compare them with those after traditional percutaneous PS fixation.

Materials And Methods

Patient and information

This is a comparative study of a consecutive series of patients with type A lumbar fractures without neurologic defects treated with posterior stabilization at our department of the Second People's hospital of Wuhu. Inclusion criteria included: (1) single-level traumatic lumbar fracture (L1-L5); (2) Type A fracture (compression fracture) in accordance with the AO classification(Magerl et al. 1994); (3) no neurologic deficit (ASIA E); (4) received PPSF or percutaneously CBT operation; (5) followed up for at least one year; and (6) no other significant injuries. Exclusion criteria were as follows: multiple levels of lumbar fractures; long-segment screw fixation or with screw instrumentation performed in the fractured segment; anterior–posterior surgeries; combined posterior decompressed surgeries; history of previous back surgery; and non-traumatic spinal fractures (e.g., fractures caused by tumour or metastases).

22 consecutive patients (8 men, 14 women) with type A lumbar fractures without neurologic defects treated with percutaneously short-segment 4 cortical bone trajectory screw fixation between September 2019 and August 2020 were followed up for at least one year (PCBT group). A historical control group comprised 24 consecutive patients (13 men, 11 women) whom underwent traditional percutaneously short-segment 4 pedicle screw fixation between October 2018 and August 2019 was performed by the same surgeons who conducted the surgeries in the CBT group, and these patients were also followed up for at least one year after surgery (PPSF group). Our study protocol was approved by the Ethics

Committee and Institutional Review Board of the Second People's hospital of Wuhu. All patients provided written informed consent.

Surgical technique

Surgeries for all the patients were performed by the senior spinal surgeons who had received special training for at least 10 years. After general anesthesia, each patient was placed in a supine position, with cushions under the iliac crests and thorax to allow the spine in a hyperextended position to obtain postural reduction. The incision site was located by fluoroscopy, and screws were inserted into the vertebra one level above and one level below the fractured level.

For the PPSF fixation group, four small incisions were made after the entry points were set. The puncture needle was placed at the outer edge of the cortex projected by the vertebral pedicle, and was then inserted along the central axis of the pedicles with proper medial and caudal inclination monitored by C-arm. The inner core was pulled out and a guide wire was inserted. Pedicle screws with a suitable size were slid over the guide wires and inserted into the vertebra. The connecting rod was placed percutaneously with the assistance of screw extenders to strut and reduce the injured vertebra.

In the PCBT group, a total of two separated minimal midline incisions overlying the target spinal segment were made. The entry points for PCBT screws are approximately located at 5 o'clock orientation of the left pedicle and 7 o'clock orientation of the right pedicle, with an approximately 10 degrees medial to lateral angulation and 25 degrees cranially in the sagittal plane. A pedicle pilot hole was made using a guide wire and a dilator. After CBT screw insertion, a rod was inserted percutaneously using a special placement system and subsequently used to reduce the compressed vertebra (Fig.1).

All steps of screw fixation were performed under C-arm fluoroscopic image guidance. There was no screw instrumentation performed in the fractured vertebra. Normal saline was applied to clean the incision before the incision was sutured (Fig.2 and Fig.3). All the patients were routinely treated with antibiotics and started out-of-bed activities with braces 5-7 days after operation. Following discharge from the hospital, all patients were clinically and radiologically assessed in our orthopaedic outpatient clinic, with a mean follow up of 16.1 months (range, 12-22 months).

Radiographic and clinical assessment

Preoperative, postoperative, and most recent follow-up radiographs of all the enrolled patients were evaluated. The patients' injury details and AO classification were calculated to evaluate the fracture (shown in table 1). Vertebral wedge angle (VWA) was defined as the angle of the superior endplate and inferior endplate of the fractured vertebra. Sagittal index was calculated as the percentage of anterior vertebral body height relative to the posterior vertebral body height at the fracture level (Fig. 4) (Hartmann et al. 2012).

Clinical outcomes (including surgery time, blood loss, hospital stay, incision length, X-ray exposures and complications) were compared between two groups. The visual analogue scale (VAS: 0 = no pain at all, 10 = worst pain imaginable) scores were used to evaluate the pain before, 5 days after surgery, and at the end of follow-up. The Oswestry Disability Index (ODI, 0% = minimal to 100% = maximal disability) scores were used to evaluate patients' daily life functions also before, 5 days after surgery, and at the end of follow-up. The assessment of the entire radiographic and clinical index was conducted by two independent researchers who had no involvement in the treatment.

Statistical analysis

All the data were presented as mean ± standard deviation (SD) or proportion, stratified by surgery approach. While categorical variables were examined with chi-square or Fisher's exact test, continuous variables between groups were compared by using the Independent-Sample Test. Afterwards, multivariable liner regression analyses (Method: Enter) were used to compare clinical and radiographic values separately between PPSF group and PCBT group, adjusting for AO classification alone and for multiply independents (including age, sex, BMI, AO classification, follow-up and fracture level). P values less than 0.05 were considered statistically significant. All statistical analyses were conducted using with IBM SPSS Statistics, version 25.

Results

This comparative study consisted of 46 patients, 21 male and 25 female, with a mean age of 56.76 years (range from 45 to 71 years). The mean follow-up period was 16.1 months (range,12-22 months). Baseline characteristics of the enrolled patients were compared between the PPSF and PCBT groups (as shown in Table 1). There was no significant difference in terms of mean age, sex ratio, mean BMI, follow-up and injured vertebrae segments between PPSF group (24 patients) and PCBT group (22 patients). However, the types of fractures of the two groups were significantly different: there were type A1 fractures in 21 patients and type A2 fractures in 3 patients in PPSF group, while in PCBT group 15 patients were type A1, 2 patient was type A2 and 5 patients were type A3.

Clinical evaluation

While incision length and hospital stay in the PCBT group were significantly better than the PPSF group ($p < 0.05$), no statistical difference was observed between two groups in the aspect of blood loss, X-ray exposure and surgery time, without adjustment or adjusted for AO classification ($p > 0.05$) (Table 2). However, after adjusted for age, sex, BMI, AO classification, follow-up and fracture level, the difference between the two groups in hospital stay was no longer significant ($p > 0.05$), and in the other hand, the surgery time and X-ray exposure of the PCBT group were notably higher than the PPSF group (145.00±18.83 min vs. 138.97±16.02 min; 26.50±4.85 times vs. 24.82±6.17 times respectively; $p < 0.05$ each). The average VAS and ODI scores in both the two groups were improved greatly 5 days after operation until the last follow-up. Patients in the PPSF group had comparable improvement either at 5 days after operation or at last follow-up in comparison to the PCBT group, with or without adjustment ($p > 0.05$).

Radiographic evaluation

As shown in table 3, before adjustment there was no significant difference in the radiographic data between PPSF and PCBT group ($p > 0.05$). All the average preoperative, postoperative, last follow-up, restored and maintained VWA and sagittal index were similar in both PPSF and PCBT group. However, after multiply adjustment, while the maintenance of VWA and sagittal index of the two groups till the last follow-up was still comparable, PCBT group had better postoperative restoration in terms of VWA than the PPSF group ($p < 0.05$).

Complications

In the PPSF group, one patient had one L2 pedicle screw loosened. This patient felt moderate back pain when walked, and this symptom disappeared when the fixation system was removed at 13 months postoperatively. Cerebrospinal fluid leakage occurred in a 51-year-old man with a L2 type A1 fracture, and this did not result in any symptom after suturing the anadesma closely intraoperatively. There were no complications occurred in the PCBT group. There were no significant differences between groups in the rate of complications. An illustrative case is presented in Figure 5.

Discussion

The current study shows that PCBT technique led to smaller incisions and shorter hospital stay, yet equivalent clinical outcomes compared with traditional PPSF surgery. The average incision length of PCBT was only 7.17±0.72 cm, significantly shorter than that of the PPSF group (14.74±1.35 cm). This advantage would lead to less muscular damage, which was correlated with better recovery after surgery (Marengo et al. 2018). In our study, this may be associated with the obviously shorter period of hospital stay in the PCBT group (9.92±7.53 days vs. 13.85±7.53 days in the PPSF group), although this difference between groups was no longer significant after adjustment. Nonetheless, it should also be noted that PCBT technique in our study had longer surgery time and more X-ray exposures. This was different from the clinical data reported by Nicola Marengo et al(Marengo et al. 2018) in which CBT technique provided less Radiation DAP, blood loss, and Surgical time compared to PS procedure in posterior lumbar interbody fusion. The possible explanation for the result in our study may be that there is no previous experience for surgeons to conduct this totally new technique and it still needs time and experience to master the whole procedure.

In this study the average pain intensity VAS scores and ODI were significantly improved after surgery and at the last follow-up in both groups. There was no significant difference between groups in the short- and long-term improvement with or without adjustment, suggesting that PCBT technique yielded equivalent clinical outcomes to the PPSF approach. Hironobu Sakaura et al. (Sakaura et al. 2018) also reported similarly equal outcomes among patients with 2-level degenerative lumbar spondylolisthesis: The mean JOA scores recovery rate (54.4%, from 12.3 points before surgery to 21.1 points at the latest follow-up) in the CBT group was comparable with that of PS group (51.8%, from 12.8 points to 20.4 points). From a small clinical case series study, Yiren Chen et al.(Chen et al. 2018) reported that CBT fixation for degenerative lumbar disease showed a decrease of 27 from the baseline ODI at six to eight months, which is comparable to changes from the baseline ODI reported in three large clinical trials following traditional pedicle screw fixation. Likewise, Shiyuan Shi et al. found no significant difference in the improvement of VAS scores after surgery between CBT group and traditional PS group in the treatment of elderly patients with lumbar spinal tuberculosis(Shi et al. 2018). However, in a prospective cohort of 40 patients with monosegmental degenerative disease, Nicola Marengo et al. reported that CBT-PLIF technique provided significantly better clinical scores (ODI and VAS) compared to PS-PLIF technique, and this significant difference is still present one year after surgery(Marengo et al. 2018).

Regarding radiographic outcomes, before adjustment we found no significant difference in either the postoperative restoration or the maintenance till the latest follow-up of both VWA and sagittal index between the two groups ($p > 0.05$). Notably, after adjustment for all the possible confounders including BMI, fracture level, fracture type and follow-up period, patients underwent PCBT technique had significantly better postoperative restoration in VWA compared with PPSF group ($p < 0.05$). Although more follow-up studies in larger patient populations are needed, this result suggests that PCBT fixation may be superior to traditional PPSF technique in intraoperatively promoting the recovery of the height of the compressed vertebra. Since Santoni et al. (Santoni et al. 2009) firstly reported that the cortical bone trajectory (CBT) screw technique demonstrated a 30% increase in uniaxial yield pull-out load relative to the traditional pedicle screws, several biomechanical and morphometric studies comparing the properties of CBT fixation with traditional pedicle screws technique have been performed. Calvert et al.(Calvert et al. 2015) conducted a biomechanical study in 10 fresh frozen human lumbar spines and demonstrated that CBT screws provided stiffness in flexion, extension, lateral bending and axial rotation tests similar to that provided by traditional pedicle screws in cases of rescue screw constructs. Baluch et al. (Baluch et al. 2014) also performed a human cadaveric study on 17 vertebral levels (T11-L5) and then performed quantitative CT scans to compare the fixation strength of cortical screws under physiological loads with traditional pedicle screws. They found that the force necessary to displace CBT screws were significantly greater than the traditional screws. Matsukawa et al. (Matsukawa et al. 2014b) measured the insertional torque of CBT intraoperatively in 48 patients and demonstrated that the insertional torque of CBT screws was 2.01 times higher than that of the traditional screw technique, suggesting an advantage for CBT screws. However, it should be noted that there is still a lack of comprehensive and robust evidence for CBT screws in directly evaluating the comparative biomechanical performance to PS fixation in traumatic vertebral fractures.

Screw loosening is a very common complication for PS fixation, and the rate of screw loosening has been estimated to exceed 60% in patients with osteoporosis (Delgado-Fernandez et al. 2017). The internal fixation of CBT technology can increase the bone screw interface strength as it allows the screw to be fully in contact with the cortical bone. Therefore, CBT screws were conceived as an alternative method to traditional pedicle screw fixation, particularly for stabilization of lower lumbar segments with definitive osteoporosis (Sansur et al. 2016). The equivalent or superior biomechanical properties of CBT screws may be associated with the lower rate of screw loosening reported in the few clinical studies. Gonchar et al.(Delgado-Fernandez et al. 2017) reported a retrospective comparative study of 100 CBT versus 63 traditional pedicle screws in patients who had spinal deformity, degenerative disease, osteoporotic vertebral collapse or trauma. There was one case (1%) of screw loosening in the CBT group versus 16 cases (25%) in the traditional pedicle group. They (Phan et al. 2015) also conducted a prospective comparative study of 30 CBT and 30 traditional pedicle screws patients undergoing posterior lumbar interbody fusion surgery, and reported a similarly high screw loosening rate in the traditional pedicle fixation group (six cases vs. one case). In a retrospective study of 12 patients with single-level lumbar spondylolisthesis who underwent posterior or transforaminal lumbar interbody fusion surgery using CBT screws (Mizuno et al. 2014), no loose screws were detected after the 20-month follow-up. In our study, while no case of screw loosening was detected in the PCBT group, there was one case occurred in the PPSF group.

Moreover, the incidence of pedicle screws misplacement was reported to range from 21 to 40% in despite of the introduction of navigation equipment (Laine et al. 2000; Gertzbein and Robbins 1990; Weinstein et al. 1988). This would lead to a series of serious complications, such as neurological injury, cerebrospinal fluid leakage and abdominal artery injury (Ouchida et al. 2020; Zhao et al. 2018). At this point, CBT technique may significantly decrease the risk of neurovascular injury, as the trajectory of lumbar CBT screws is placed with medial to lateral angulation, which allows the insertion to depart from the nerve roots, dural sac and anterior vascular structures(Phan et al. 2015). This may well explain the lower rate of neurovascular damage of CBT patients currently reported in clinical studies. In a retrospective comparative study of 16 CBT versus 19 traditional PS screws in patients undergoing open posterior lumbar interbody fusions, Okudaira et al.(Phan et al. 2015) reported that while no complications were noted in the CBT group, there was one case of deep infection and permanent neural damage in the traditional pedicle screw group. Hironobu Sakaura et al(Sakaura et al. 2018) designed a comparative study consisted of 22 patients with 2-level DS underwent 2-level PLIF with CBT screw fixation (CBT group, mean follow-up 39 months) and a historical control group of 20 patients who underwent 2-level PLIF using traditional PS fixation (PS group, mean follow-up 35 months). They found that the incidence of intraoperative and early postoperative complications (including dural laceration, symptomatic hematoma and misplacement of screws) was higher in the PS group than in the CBT group, though no significant difference between the groups was found. In this comparative study, while no complications were noted in the PCBT group, there was 1 case with cerebrospinal fluid leakage in the traditional PPSF group. This indicates that PCBT is a safe technique with insignificantly fewer complications compared with traditional PPSF instrumentation.

To the best of our knowledge, we are the first to apply this minimally invasive PCBT technique in the surgical treatment of patients with lumbar fractures. Its application values are as follows. Firstly, it reduces the number of incisions, significantly shortens the incision length and minimizes soft tissue injury. These can contribute to a shorter period of hospital stay and consequently reduce the medical costs. Secondly, we find that this technique is feasible as PCBT screws can be successfully inserted under intraoperative fluoroscopy in a similar way to traditional PPSF technique. The surgery time and X-ray exposure times of PCBT were also comparable to those of PPSF fixation. Finally, it provides clinical data for the treatment of lumbar fractures and demonstrates that PCBT technique can yield equivalent or superior clinical outcomes compared with traditional PPSF fixation. Therefore, it can be considered as an alternative method to traditional PPSF fixation with fewer complications, particularly for the treatment of osteoporotic fractures.

However, our study also has some shortcomings. All of the enrolled patients were only followed up for less than 2 years, thus, the long-term clinical results of PCBT fixation were still uncertain. Therefore, the application of this new approach should be conducted with caution. Also, the number of enrolled patients was limited, and in the future large longitudinal studies should be designed to further testify the safety and feasibility of this new approach. Only patients more than 45 years old were reviewed for this retrospective study, therefore, it is still unclear whether this technique can have similarly inspiring outcomes among younger patients.

Conclusion

The present study showed that percutaneous cortical bone trajectory screw fixation is a safe and feasible method for the treatment of lumbar fractures without neurological deficits. It resulted in smaller incisions and shorter period of hospital stay, yet yielded equivalent or superior clinical and radiographic outcomes compared to the traditional percutaneous pedicle screw fixation surgery.

Declarations

Funding (None)

Conflicts of interest/Competing interests (The authors of this study have no conflict of interests.)

Availability of data and material (The datasets used or analysed during the current study are available from the corresponding author on reasonable request.)

Code availability (Not applicable)

Ethics approval (This study received approval from the Ethics Committee and Institutional Review Board of the Second People’ hospital of Wuhu.)

Consent to participate (Informed consent was obtained from all individual participants included at the beginning of the study.)

Consent for publication (The manuscript has neither been submitted to other journals, nor been published previously (partly or in full). All the authors listed have approved the manuscript that is enclosed.)

Authors' contributions (Zhangan zheng and Li Zhang wrote the manuscript and contributed to the conception of the study; they contributed equally to this paper; Yu Zhu and Jun Chen performed the data analyses and interpretation; Zheng Yan, Pengpeng Zhang and Chunhong Liu collected and assembled the data; Yinshun Zhang, Hongguang Xu and Bing Wang contributed significantly to manuscript preparation and constructive discussions; Zhaoliu Gui, Shuangtao Xue and Zongsheng Yin contributed to the revision and final approval of article.)

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Tables

Table 1 Baseline characteristics of the PPSF and PCBT groups

	PPSF group	PCBT group	p-value
No. of patients	24	22	
Mean age (years)	56.59±6.21	57.33±6.20	0.718
Sex ratio (M/F)	13/11	8/14	0.057
Mean BMI (kg/m^2)	23.90±1.96	24.30±2.56	0.571
Follow-up(months)	16.04±4.10	16.26±5.53	0.953
Fractured level (L1/L2/L3/L4)	14/7/3/0	10/7/4/1	0.115
AO classification (A1/A2/A3)	21/3/0	15/2/5	0.033*

*Statistically significant ($p < 0.05$)

Table 2 Comparison of clinical parameters between the two groups

	PPSF group	PCBT group	p-value	p-value¹	p-value²
Blood loss (ml)	54.36±22.22	68.33±2.81	0.060	0.141	0.525
Hospital stays (day)	13.85±7.53	9.92±7.53	0.034*	0.074	0.126
Incision length(cm)	14.74±1.35	7.17±0.72	0.000*	0.000*	0.000*
X-ray exposure (times)	24.82±6.17	26.50±4.85	0.393	0.696	0.034*
Surgery time (min)	138.97±16.02	145.00±18.83	0.280	0.052	0.042*
VAS scores					
Preoperative	7.08±0.74	6.58±0.90	0.061	0.075	0.415
5 days postoperative	2.85±0.84	2.33±0.78	0.067	0.171	0.346
Last Follow-up	1.03±0.71	0.67±0.65	0.124	0.299	0.144
Improvement 5 days postoperatively	4.23±0.96	4.25±1.29	0.956	0.837	0.572
Improvement at last follow-up	6.05±0.97	5.92±1.17	0.691	0.463	0.608
ODI					
Preoperative	0.634±0.056	0.623±0.063	0.585	0.844	0.610
5 days postoperative	0.166±0.032	0.153±0.032	0.226	0.469	0.319
Last Follow-up	0.061±0.035	0.055±0.039	0.616	0.680	0.743
Improvement 5 days postoperatively	0.468±0.068	0.470±0.059	0.916	0.993	0.773
Improvement at last follow-up	0.573±0.056	0.568±0.070	0.821	0.794	0.879

VAS = visual analogue scale; ODI = Oswestry Disability Index; VAS Improvement 5 days postoperatively = absolute value of 5 days postoperative VAS - Preoperative VAS; VAS Improvement at last follow-up = absolute value of Last Follow-up VAS - Preoperative VAS; ODI Improvement 5 days postoperatively = absolute value of 5 days postoperative ODI - Preoperative ODI; ODI Improvement at last follow-up = absolute value of Last Follow-up ODI - Preoperative ODI;

P-value¹ == p-value after adjustment for AO classification;

P-value² = p-value after adjustment for including age, sex, BMI, AO classification, follow-up and fracture level;

*Statistically significant ($p < 0.05$)

Table 3 Summary of radiographic measurements

	PPSF group	PCBT group	p-value	p-value¹	p-value²
VWA					
Preoperative	14.38±5.65	14.83±6.44	0.817	0.970	0.000*
Postoperative	6.97±3.62	6.83±3.93	0.908	0.908	0.000*
Last Follow-up	9.15±4.48	8.75±5.38	0.795	0.870	0.000*
Restoration	7.41±4.22	8.00±4.20	0.673	0.889	0.004*
Maintenance	5.23±3.55	6.08±5.52	0.529	0.759	0.123
sagittal index					
Preoperative	0.701±0.117	0.633±0.157	0.115	0.291	0.000*
Postoperative	0.816±0.073	0.815±0.114	0.994	0.783	0.001*
Last Follow-up	0.796±0.086	0.797±0.117	0.962	0.911	0.004*
Restoration	0.115±0.105	0.182±0.126	0.069	0.166	0.068
Maintenance	0.095±0.098	0.164±0.151	0.069	0.179	0.289

VWA= Vertebral wedge angle; VWA restoration = absolute value of Postoperative VWA - Preoperative VWA; VWA maintenance = absolute value of Last follow-up VWA - Preoperative VWA; sagittal index restoration = absolute value of Postoperative sagittal index - Preoperative sagittal index; sagittal index maintenance = absolute value of Last follow-up sagittal index - Preoperative sagittal index;

P-value¹ == p-value after adjustment for AO classification;

P-value² = p-value after adjustment for including age, sex, BMI, AO classification, follow-up and fracture level;

*Statistically significant ($p < 0.05$)

Figures

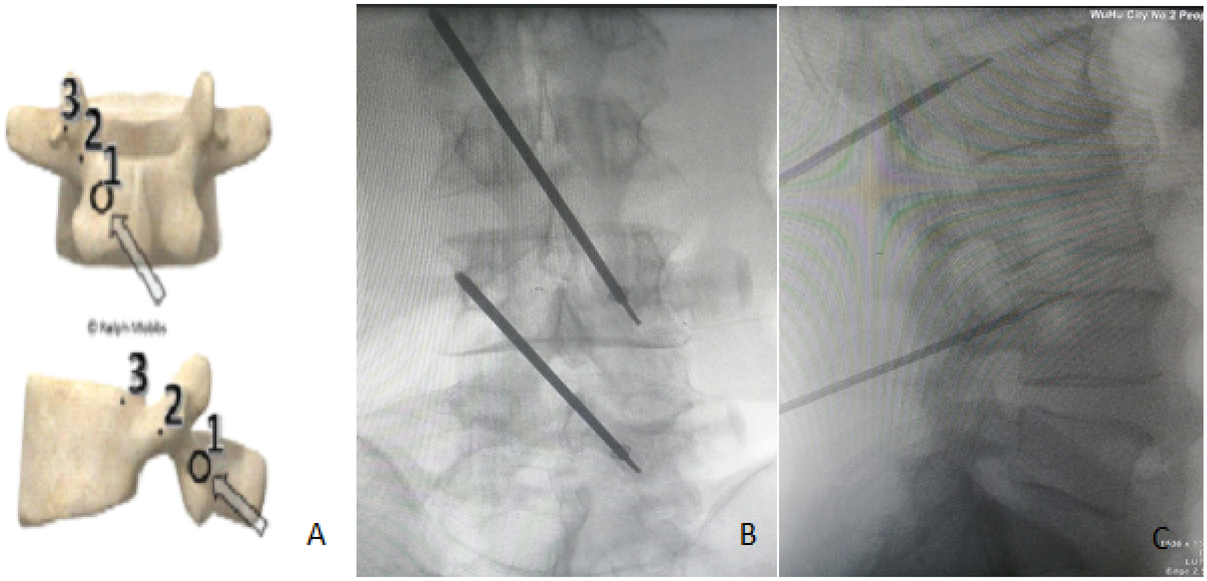

Figure 1

(A) Model showing the starting point for the PCBT technique (Point 1), Points 2 and 3 demonstrate the trajectories that the surgeon can use during lateral or anteroposterior radiography, respectively[15]. (B) Anteroposterior view and (C) Lateral view of the puncture needle in the neutral position.

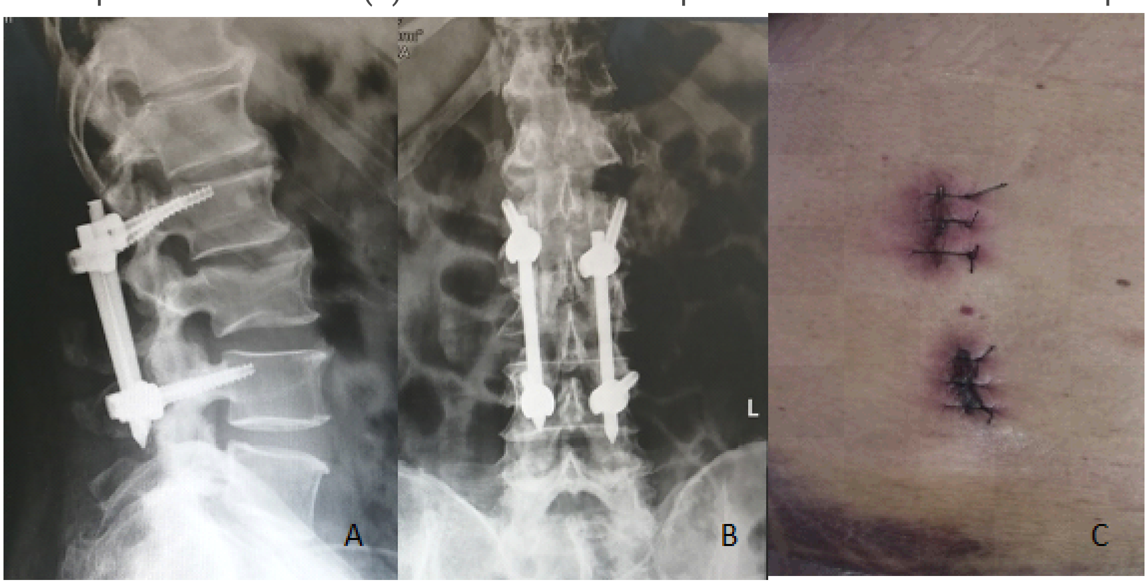

Figure 2

A 65-year-old man underwent PCBT for L3 type A1 fracture. Radiographs were obtained 3 days after surgery. A: Lateral view. B: Anteroposterior view of the patient in the neutral position. C: The incision of PCBT approach.

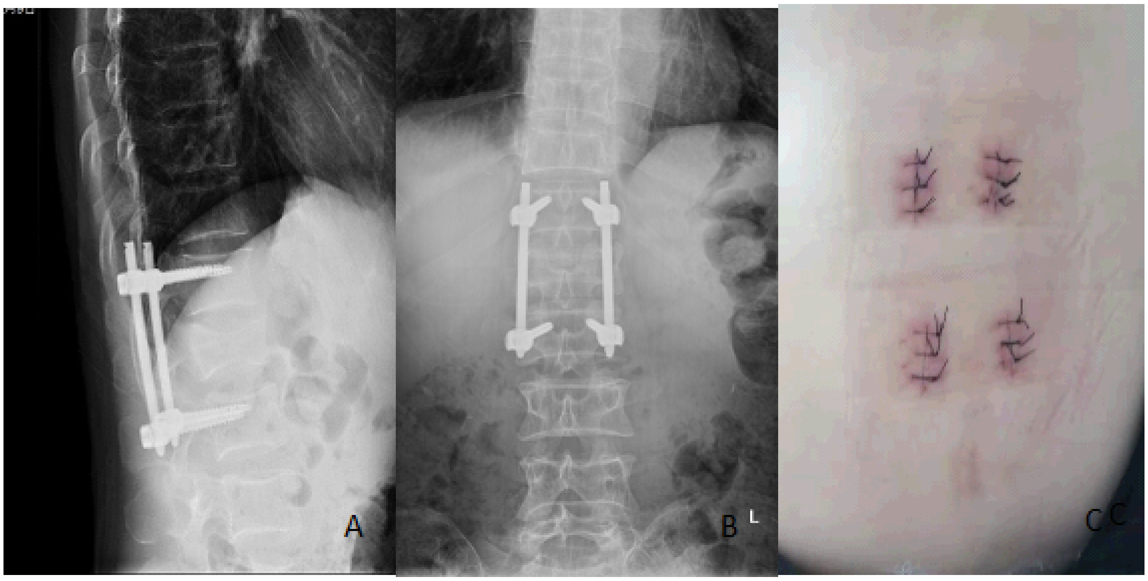

Figure 3

A 58-year-old woman underwent PPSF for L1 type A1 fracture. Radiographs were obtained 6 days after surgery. A: Lateral view. B: Anteroposterior view of the patient in the neutral position. C: The incision of PPSF approach.

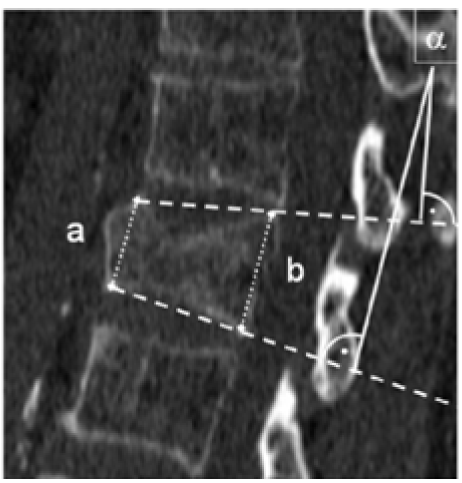

Figure 4

Sagittal index=a/b; Wedge Angle = α;

Figure 5

A 63-year-old man underwent PPSF for L1 type A1 fracture. (A and B) The Lateral and Anteroposterior radiographs were obtained 5 days after surgery. (C and D) The Lateral and Anteroposterior radiographs obtained at the 2-month follow-up showed the occurrence of L2 pedicle screw loosening.