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C-arm Oblique View Assisted Percutaneous Kyphoplasty (PKP) for Treating Osteoporotic Vertebral Compression Fractures

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Abstract

Objective: To assess the efficacy of C-arm oblique radiography-assisted percutaneous kyphoplasty (PKP) in the treatment of osteoporotic vertebral compression fractures (OVCF) and its impact on radiation exposure for both surgeons and patients.

Methods: In total, 192 patients with single-segment OVCF were included. Traditional anteroposterior (AP) and lateral fluoroscopy were used for puncture positioning in 86 cases (AP-lateral group), whereas C-arm oblique fluoroscopy was used in 106 cases (oblique group). the surgical time and the number of fluoroscopies were recorded. DR radiography was used to measure vertebral height, differences in vertebral compression and Cobb angle before and after surgery were compared. Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores were recorded to assess surgical efficacy.

Results: The oblique group had fewer intraoperative fluoroscopies (18.02±5.86) compared to the AP-lateral group (29.09±7.67); and shorter surgery time (29.67±11.32 min vs. 36.35±9.32 min), with both differences being statistically significant ($P<0.05$). Three months post-surgery, the VAS pain scores in the AP-lateral group were 2.19±1.30 and 2.26±1.30 in the oblique group, both significantly lower than pre-surgery scores, with statistical significance ($P<0.05$). However, there were no significant differences between the groups ($P>0.05$).

Conclusion: C-arm oblique view assisted PKP can reduce surgery time, improve puncture accuracy, and decrease ionizing radiation exposure, effectively treating OVCF.

Introduction

With the increasing aging population[1], Osteoporosis (OP) is a metabolic bone disorder characterized by reduced bone mass and compromised bone microarchitecture. Its etiology is multifactorial, involving age, sex, genetics, nutrition, and lifestyle. With advancing age, bone metabolism becomes imbalanced, with bone resorption outpacing bone formation, and resulting in bone loss[2]. Additionally, estrogen deficiency, vitamin D insufficiency, and inadequate calcium intake further exacerbate this process. Osteoporotic Vertebral Compression Fractures (OVCFs) are a common complication of OP, in which decreased vertebral bone density and quality make the vertebrae susceptible to compression fractures from minor external forces. Pathological features include vertebral height loss, kyphotic deformity, and refractory back pain, which significantly impair patients' quality of life and survival rates[3]. Currently, PKP is the primary treatment for OVCF.

Traditional PKP surgery using mobile C-arm fluoroscopy exposes patients and surgeons to prolonged radiation and is associated with complications such as bone cement leakage due to inaccurate punctures[4]. Achieving precise and rapid pedicle puncture while minimizing fluoroscopy time and surgery duration is crucial for successful outcomes. Advanced computer-assisted surgical technologies[5], including surgical robots[6], real-time ultrasound navigation[7], and O-arm navigation[8], offer enhanced precision and reduced radiation exposure. However, their high costs and complex procedures limit their widespread adoption in primary hospitals[9].

To address these challenges, our team has developed a C-arm oblique imaging technique to assist PKP surgery. This method provides precise indications for pedicle puncture points and guidance for puncture paths, aiming to achieve accurate, rapid, and safe punctures. This study investigated the efficacy of C-arm oblique imaging-assisted PKP for treating OVCF and its impact on radiation exposure for both surgeons and patients during surgery.

Materials and Methods

Informed Consent

Informed consent was obtained from all patients participating in the study so that their data could be used for research purposes.In addition to indicating their consent by responding to the invitation, all participants provided written informed consent.

Patient Selection

We conducted a retrospective study of 192 OVCF patients who underwent PKP between January 2023 and December 2023. The patients were divided into two groups based on the intraoperative imaging method: the traditional AP and lateral fluoroscopy positioning group (84 cases) and the C-arm oblique imaging-assisted positioning group (96 cases) (Table 1).

Inclusion criteria:

1. Preoperative lumbar radiography, CT, and MRI confirmed a fresh single-segment fresh lumbar fracture.
2. Diagnosed with OP.
3. Clear history of trauma, clinical symptoms of low back pain, and restricted movement.

Exclusion criteria:

1. Pedicle destruction.
2. Combined spinal cord injury.
3. Unable to cooperate with questionnaire scoring and postoperative follow-up visits.

Surgical Techniques

The AP-lateral group:

The AP and lateral group underwent traditional C-arm guided PKP surgery. The patients were placed in the prone position, with routine disinfection and draping. A surface grid locator was used to mark the pedicle of the target vertebrae. Local anesthesia was administered with a mixture of 2% lidocaine and 10 mg/ml ropivacaine. The puncture position and angle were adjusted under fluoroscopy until accurate, positioning was achieved. The puncture needle was inserted percutaneously along the pedicle path to the anterior third of the vertebra, a

Table 1: General information

		AP-lateral group	oblique group	P value
Gender	Male	12	21	-
	Female	74	85	-
Hight (cm)		160.80±4.64	160.98±4.39	P>0.05
Weight (kg)		57.27±7.3	57.95±7.74	P>0.05
Age		68.42±11.81	69.46±10.84	P>0.05
Responsible Vertebrae	T7	1	1	-
	T8	2	1	-
	T9	2	1	-
	T10	1	0	-
	T11	5	12	-
	T12	18	25	-
	L1	15	16	-
	L2	23	27	-
	L3	15	17	-
	L4	4	3	-
	L5	0	3	-

Kirschner wire was placed, followed by the vertebroplasty guidance system, and the bone cement delivery device was inserted. Under fluoroscopic guidance, the balloon catheter was inserted and inflated to restore vertebral height. The contrast agent was subsequently withdrawn, and the balloon was retracted and removed. Under multiple C-arm fluoroscopic observations, bone cement in a viscous state was injected through the vertebroplasty guide. Once the bone cement had cooled and hardened, the working channel was removed, and the surgical incision was dressed with a sterile wound dressing.

The oblique group:

The oblique group underwent PKP surgery assisted by C-arm oblique imaging. The patients were placed in the prone position and positioned under C-arm X-ray fluoroscopy. The head-tail tilt of the C-arm was adjusted to align the endplate shadows into a straight line to determine the head-tail angle for the puncture needle. Preoperatively, the angle of internal inclination and the depth of puncture were determined via three-dimensional CT reconstruction. The oblique angle of the C-arm X-ray machine was adjusted to match this angle. For the endoprosthetic approach, the puncture point was positioned within the circular projection of the pedicle axis. The head tilt angle of the puncture needle was aligned with the medial tilt angle, ensuring that the puncture path was perpendicular to the upper endplate line. The needle was then inserted towards the center of the circle to the predetermined depth. By contrast, for the extra-axial puncture route, the puncture point was set at the lateral edge of the axial circular projection of the pedicle. The head tilt angle and inward tilt angle of the puncture needle were maintained, with the puncture path being perpendicular to the shadow of the upper endplate and tangent to the outer edge of the circular projection of the pedicle, advancing gradually to the measured depth (Figure 1). The subsequent operative procedure was identical to that used in the AP-lateral group (Figure 2 & 3).

Therapeutic Evaluation

The surgical time and number of fluoroscopies were recorded. DR imaging was used to measure vertebral height and compare the degree of vertebral compression and Cobb angle before and after surgery. VAS scores and ODI scores were recorded to evaluate surgical efficacy.

Statistical Methods

Statistical analysis was conducted using the Stata software. Measurement data were expressed as mean ± standard deviation ($\bar{x}\pm s$). ANOVA or paired t-tests were used for repeated measures analysis. Statistical significance was set at $P<0.05$.

Results

All the patients successfully completed the surgery. Satisfactory surgical outcomes were achieved in both the oblique group and the AP and lateral group. However, the oblique group demonstrated superiority in operative time, intraoperative blood loss, and number of fluoroscopies. The

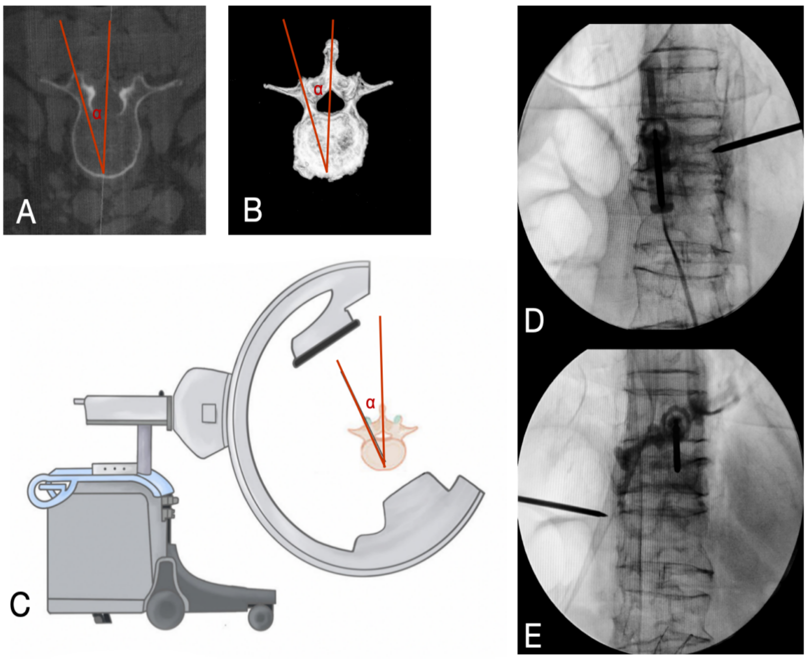

Figure 1: A, B) Measurement of the angle α of the midline of the spinous process adjacent to the axial position of the pedicle in three-dimensional CT scan. **C)** Flipping the c-arm x-ray machine to angle α to obtain axial images of the pedicles. **D, E)** Showing the puncture needle pointing towards the centre of the circular projection of the pedicle in the axial view of the pedicles.

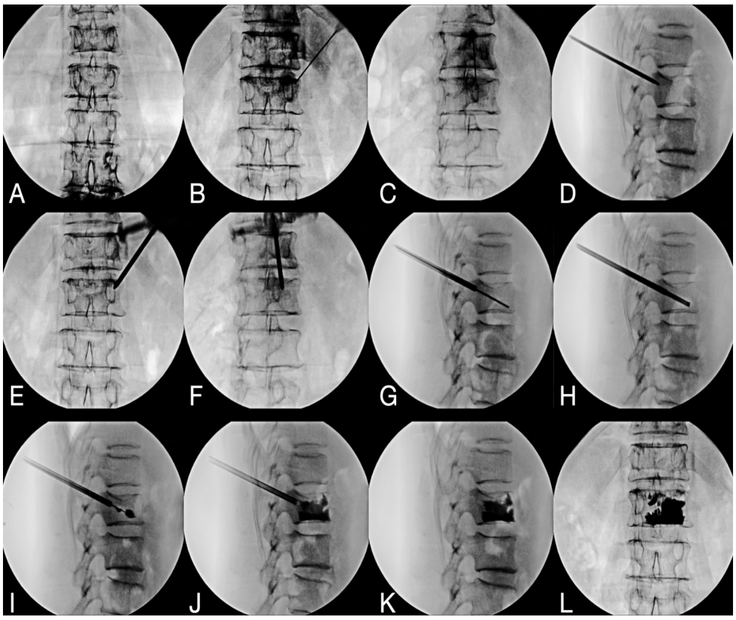

Figure 2: A) C-arm AP view to locate the target segment. **B, C)** Long needle puncture to target pedicle with local anesthesia, and verify the puncture angle and depth. **D, E, F)** Adjust puncture position and angle under C-arm lateral, AP and oblique views, inserting through the pedicle to reach the anterior third of the vertebral body. **G)** Remove the puncture needle, insert a Kirschner wire for guidance. **H)** Insert vertebroplasty guide system. **I**) Introduce balloon catheter, inflating the balloon to restore vertebral height. **J)** Slowly inject bone cement in successive steps. **K, L)** Withdraw working channel, C-arm lateral and AP views show restored vertebral height and satisfying cement distribution.

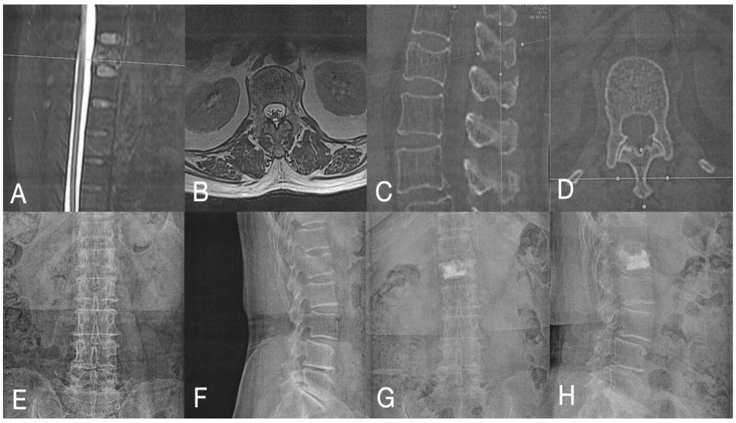

Figure 3: A, B) Female patient, 61 years old, preoperative lumbar MRI showing bone marrow edema at L1. **C, D)** Preoperative CT showing discontinuity in L1 vertebra; **E, F)** Preoperative lumbar X-rays (frontal and lateral) showing compression of the anterior and middle columns of the L1 vertebra; **G, H)** Unilateral transpedicular approach with C-arm oblique view assisting balloon kyphoplasty, postoperative lumbar X-rays (frontal and lateral) showing good cement distribution and restored vertebral height.

oblique group required fewer fluoroscopies (18.02±5.86) than the AP and lateral group (29.09±7.67). The surgery time was shorter in the oblique group (29.67±11.32 min) compared to the AP and lateral group (36.35±9.32 min), and intraoperative blood loss was less (3.68±2.51 ml vs. 5.88±1.75 ml). These differences were statistically significant (P<0.05) (Table 2).

VAS scores at 3 months post-surgery were significantly lower than pre-surgery in both groups, with the AP and lateral group at 2.19±1.30 and the oblique group at 2.26±1.30 (P<0.05). ODI scores were also significantly reduced post-surgery, with the AP and lateral group at 17.29±5.45 and the oblique group at 18.63±5.85 (P<0.05). There were no statistically significant differences between the groups in terms of pre- and post-surgery VAS and ODI scores (Table 3).

The anterior vertebral height and Cobb angle of the lumbar spine were measured from radiographs by two experienced spine surgeons, with the average taken. Both groups showed a significant increase in anterior vertebral height post-surgery compared to pre-surgery (P<0.05), but the difference between groups was not. Both groups also

Table 2: Comparisons of Surgical Parameters and Complications

		AP-lateral group	oblique group	P value	t value
Surgical Time (min)		36.35±9.32	29.67±11.32	P<0.05	4.4076
Intraoperative Blood Loss (ml)		5.88±1.75	3.68±2.51	P<0.05	6.9318
Intraoperative X-ray Fluoroscopy Views		29.09±7.67	18.02±5.86	P<0.05	11.3971
Bone Cement Usage		4.56±1.26	4.62±1.15	P>0.05	-0.3587
Complications	Adjacent Vertebral Fracture	0	0	-	-
	Bone Cement Leakage	4	1	-	-
	Cerebrospinal Fluid Leak	0	0	-	-
	Postoperative Chronic Pain	4	1	-	-
	Infection	0	0	-	-

Table 3: Preoperative and postoperative VAS and ODI comparisons

		AP-lateral group	oblique group	P value	t value
VAS	Pre-op	7.52±1.32	7.33±1.26	P>0.05	1.0334
	Post-op	2.19±1.30	2.26±1.30	P>0.05	-0.3710
	P value	P<0.05	P<0.05		
ODI	Pre-op	40.01±5.52	39.34±5.95	P>0.05	0.8033
	Post-op	17.29±5.45	18.63±5.85	P>0.05	-1.6280
	P value	P<0.05	P<0.05		

Table 4: Preoperative and postoperative Radiological measurements

		AP-lateral group	oblique group	P value	t value
AP Height of the Vertebral Body	Pre-op	18.24±5.52	18.19±4.57	P>0.05	0.0762
	Post-op	20.31±3.69	20.60±3.37	P>0.05	-0.5676
	P value	P<0.05	P<0.05		
Cobb	Pre-op	24.38±4.87	23.76±5.55	P>0.05	0.8116
	Post-op	9.98±3.63	10.71±3.04	P>0.05	-1.5176
	P value	P<0.05	P<0.05		

showed a significant reduction in Cobb angle post-surgery (P<0.05), with no significant difference between the groups (P>0.05) (Table 4).

Discussion

With the increasing aging population, OP has become a major public health concern, significantly affecting the health of middle-aged and elderly individuals. OP is characterized by reduced bone density, deterioration of bone tissue, disruption of bone microarchitecture, compromised bone strength, and an increased risk of fractures[10]. In individuals with OP, OVCF often occurs following minor trauma or falls, typically presenting with symptoms such as lower back pain, long-term mobility limitations, and kyphotic deformity[11]. OVCF is a frequent cause of back pain among the elderly and has a substantial impact on their quality of life. The primary treatment options for OVCF include conservative and surgical approaches[12]. Conservative management typically involves prolonged strict bed rest and calcium supplementation. However, this approach is associated with prolonged treatment durations, severe pain, delayed recovery of spinal function[13], high nursing demands, and adverse effects on the respiratory, digestive, and circulatory systems, leading to poor patient compliance[14]. Surgical interventions primarily include pedicle screw fixation and PKP[15]. Pedicle screw fixation, a commonly used surgical method for lumbar fractures, provides stable fixation and restores spinal alignment. The three-column fixation system effectively controls spinal shear forces, restores the anatomical alignment of the fracture, and preserves spinal motion function. However, this technique is associated with significant trauma and postoperative pain. The screws require adequate bone grip strength. In OP patients, reduced bone quality significantly compromises screw fixation, potentially leading to screw loosening and surgical failure[16].

PKP surgery is a minimally invasive procedure that integrates the techniques of percutaneous vertebroplasty (PVP) and balloon kyphoplasty. PKP has been proven to be highly effective in treating OVCF, significantly enhancing patient outcomes[17]. This procedure is characterized by small incisions, rapid postoperative recovery, consistent therapeutic efficacy. Specifically, PKP utilizes balloon expansion to create a cavity within the fractured vertebra. This technique not only enhances vertebral strength but also minimizes the risk of cement leakage. Once the cement solidifies, it improves the compressive strength of the vertebra, restores spinal stability, alleviates pain, and facilitates patients to resume daily activities and weight-bearing tasks more quickly[18]. As a result, PKP has emerged as a well-established and widely adopted surgical option in spinal medicine[19]. The success of PKP surgery largely depends on accurate pedicle targeting and precise needle placement, guided by fluoroscopic imaging. A thorough understanding of spinal anatomy is essential for surgeons to achieve successful insertion of the expander and optimal cement distribution. During the surgical operation, puncture techniques primarily rely on the operator's tactile sense and intraoperative fluoroscopic imaging. However, C-arm fluoroscopy provides only two-dimensional images. In AP views, the operators are required to carefully judge the position of the puncture needle and the pedicle to avoid intrusion into the spinal canal. In lateral views, the direction and depth of the puncture needle require precise assessment. Despite its clinical benefits, conventional PKP procedure has several limitations. Repeated AP and lateral fluoroscopy can disrupt the procedural coherence, often reducing puncture accuracy and prolonging surgical time. Moreover, prolonged prone positioning during surgery is poorly tolerated by middle-aged and elderly patients, particularly those with cardiovascular diseases. Additionally, prolonged radiation exposure poses significant risks to both patients and medical staff. Given these challenges, conventional PKP no longer fully meets the precision and minimally invasive standards required by modern spinal surgery.

In recent years, the development of computer-assisted surgical technologies, such as the O-arm navigation system, has provided valuable intraoperative imaging and has been increasingly adopted in spinal surgeries[20]. The O-arm system provides precise puncture points, trajectories, and vertebral lesion locations[21]. However, these devices are costly and technically demanding, which limits their widespread adoption in primary hospitals. Moreover, while O-arm navigation-assisted PKP has been proven safe and effective[22], traditional PKP can be performed under local anesthesia, whereas O-arm navigation requires general anesthesia, thereby increasing anesthesia-related risks in elderly patients with OVCF[23]. Additionally, the need for a reference frame fixed to the adjacent spinous process or posterior superior iliac crest during the procedure increases surgical trauma and exacerbates postoperative pain.

To address these challenges, we developed and applied the C-arm oblique radiography technique in clinical practice. Using preoperative CT 3D reconstruction of the injured vertebrae, the angle of the pedicle's axial position relative to the midline of the spinous process can be measured. The C-arm X-ray machine was then adjusted to this angle to obtain a projected image of the pedicle that clearly shows the vertebral cortical projection. During the puncture procedure, the C-arm angle is maintained constant, keeping the longitudinal angle of the puncture needle perpendicular to the upper endplate throughout the procedure, operators were able to successfully complete the puncture and placement of the working channel. This technique eliminates the need for multiple AP and lateral radiographs to adjust the cephalad and medial inclination of the needle. With oblique radiographs, only lateral views are required to confirm the depth of channel placement. This reduces the number of intraoperative fluoroscopies, minimizes radiation exposure for patients and medical staff, decreases adjustments to the C-arm X-ray machine, and reduces the risk of contamination associated with the device. The oblique radiography angle can be precisely measured using preoperative CT, ensuring high technical reproducibility. IDLER et al. have confirmed that maintaining the puncture point within the round pedicle image during axial puncture for percutaneous pedicle screws prevents pedicle damage and potential neurological dysfunction[24].

At 3 months post-surgery, both groups exhibited significant reductions in VAS and ODI scores compared to pre-surgery levels. The AP and lateral group had VAS scores of 2.19±1.30 and ODI scores of 17.29±5.45, while the oblique group had VAS scores of 2.26±1.30 and ODI scores of 18.63±5.85 ($P<0.05$ for both). However, there was no statistically significant difference in preoperative and postoperative VAS and ODI scores between the two groups. In the radiological measurements, the changes in the anterior vertebral height and Cobb angle before and after surgery also showed similar alterations. This suggests that under both fluoroscopic positioning methods, PKP surgery can effectively alleviate thoracolumbar pain in patients with OVCF, with similar therapeutic effects. However, the oblique group had significantly fewer fluoroscopies (18.02±5.86) compared to the AP and lateral group (29.09±7.67). Additionally, the oblique group exhibited shorter surgery times (29.67±11.32 min) and lower intraoperative blood loss (3.68±2.51 ml) than the AP and lateral group (36.35±9.32 min and 5.88±1.75 ml, respectively). Given these equivalent treatment outcomes, C-arm oblique imaging can effectively shorten surgery time, reduce intraoperative blood loss, and significantly decrease the number of intraoperative fluoroscopy sessions, thereby minimizing radiation exposure for both surgeons and patients.

Conclusion

The study confirms that oblique C-arm imaging-assisted PKP surgery effectively alleviates pain symptoms in patients with OVCF. This technique is operationally simple and highly reproducible, offers advantages such as rapid positioning and high precision. Although it cannot replace three-dimensional navigation, oblique C-arm imaging significantly reduces surgery time, improves puncture accuracy, and decreases ionizing radiation exposure in simple PKP procedures. This technique is applicable not only in PKP surgery but also in vertebral body fracture repair, interbody fusion, and other surgical procedures involving pedicle fixation. However, this study was limited by the number of cases and lack of long-term follow-up data, necessitating further research to demonstrate the clinical benefits of oblique C-arm imaging-assisted PKP in large-scale applications.

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