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Anatomical feasibility study of unilateral percutaneous kyphoplasty for lumbar through the conventional transpedicular approach

An observational study using 3D CT analysis

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Abstract

The aim of the study was to discuss the significance of sex, level, age, and side in relation to the anatomical distinctions of unilateral percutaneous kyphoplasty (PKP) for lumbar osteoporotic vertebral compression fractures (OVCFs) through the conventional transpedicle approach (CTPA).

We have retrospectively collected lumbar spines (L1–L5) of 200 patients and simulated PKP on the 3D CT scans through unilateral CTPA. We have measured the distance between the entry point and the midline of the vertebral body (DEM), the puncture inclination angle (PIA), safe range of the inner inclination angles (SRA), and the success rate (SR) of puncture.

Significant differences ($P < .05$) between the male and female for L1 to L5, left and right side for L1 to L3 in the mean DEM were shown. The DEM from L1 to L5 was significantly increased ($P < .05$) from (20.6 ± 2.0) mm to (29.8 ± 2.9) mm. For L1 to L5, the right maximum PIA was significantly larger than the left. The maximum PIA and SRA in the male was significantly larger than that in the female. The SRA from L1 to L5 was significantly increased ($P < .05$) from (19.5 ± 5.9)° to (48.9 ± 8.1)°. The SR in male was significantly higher than that in female for L1 to L4. There were no significant differences in the SR between different age groups except for L4. The SR from L1 to L5 was significantly increased ($P < .05$) from 26.3% to 99.0%.

DEM was 20.6 to 29.8 mm according to different levels. The value of DEM, PIA, SRA, and SR was significantly increased from L1 to L5. No significant differences in the SR between right and left for L1 to L5, different age groups except for L4 were observed.

Abbreviations: CTPA = conventional transpedicle approach, DEM = distance between the entry point and the midline of the vertebral body, OVCFs = osteoporotic vertebral compression fractures, PIA = puncture inclination angle, PKP = percutaneous kyphoplasty, SR = success rate, SRA = safe range of the inner inclination angles.

Keywords: lumbar, osteoporotic vertebral compression fracture, percutaneous kyphoplasty, transpedicular, unilateral

1. Introduction

Osteoporotic vertebral compression fractures (OVCFs) are the most common form of fractures among the elderly in China.[1,2] Percutaneous kyphoplasty (PKP) was widely used to treat OVCFs—this technique presented with advantages of lesser trauma and hemorrhage, slight pain, few complications, and rapid recovery.[3–9] Many recent systemic reviews and clinical studies have showed that unilateral and bilateral PKP were both

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effective for the treatment of OVCFs.[10–15] Although so many puncture approaches have been devised, PKP using the bilateral or unilateral conventional transpedicle approach (CTPA) is the most commonly adopted method.[10–16]

Unilateral PKP had a shorter operation time, less radiation exposure time, and dosage of PMMA compared with bilateral PKP.[10,11,17–21] Both unipedicular and bipedicular PKP significantly increase the total VB stiffness.[13,22] When cement augmentation in unipedicular approach crosses the midline, stiffness of both sides increases comparatively and biomechanical balance is thus achieved; the imbalance of stress on the vertebral body will be avoided.[13] Given the advantages of vertebral pedicle cannulation risk, operative time, radiation exposure, and cost, this study would support the use of a unipedicular approach.[22]

Because of the anatomical distinctions among different lumbar levels, sexes, and age groups, the difficulty of unilateral puncture is not identical in all cases. It seems to be more likely to succeed for some lumbar levels, but it is risky for some other lumber levels, and a bilateral approach or other modified puncture approaches might be more appropriate.[16,23] Basic anatomical research on the differences in the success rates among different age range groups, between the sexes, and 2 sides has rarely been reported. In this study, we explored the significance of age, sex, level, and side in relation to the anatomical distinctions of unilateral PKP for lumbar OVCFs through the CTPA based on 3D CT imaging of 200 patients to provide reference points for selection of the optimal puncture approach in lumber PKP.

2. Materials and methods

2.1. Study population

The 3D CT scans of L1-L5 from 200 outpatients (98 males, 102 females), aged between 50 and 85 years (average age, 58.9 ± 7.0 years), presented with lower back pain, regardless of lower radicular symptoms were collected from May 1, 2015 to December 20, 2016. Inclusion criteria were as follows: patients experienced lower back pain that could be determined with CT scans available. Exclusion criteria were as follows: developmental abnormalities, vertebral abnormalities, and a history of lumbar surgery. A GE Light Speed VCT 64-Slice CT (GE, USA) was used for CT scans and raw data in DICOM format with a scan slice of 0.625 mm were collected. Measurement software: Aquarius iNtuition workstation was used to perform measurements with a length precision of 0.1 mm and an angles precision of 0.1°. Two spinal surgeons have measured and collected the data, and the average values were considered as the final measurement values. The study was approved by the ethics committee of General Hospital of Shenyang Military Area Command of Chinese PLA.

2.2. Puncture simulation and measurement methods

The methods were referred to previous study.[23] The distance between the entry point and the midline of the vertebral body (DEM), the puncture inclination angle (PIA), the safe range of the inner inclination angles (SRA), and the success rate (SR) of puncture was measured and compared (Fig. 1). The PIA means the angle measured between the midline and the line joining the point of entry to the target point. The SRA means angle measured between the PA and PC line. The puncture course passed through the AC line. It turned out that only with the distance between point A and B >2 mm should the puncture accomplish success. The SR is defined as the rate obtained when successful punctures are compared with all punctures involved in the methods.

2.3. Statistical analysis

All data were analyzed using the SPSS software (version 24.0; SPSS Inc., America). Differences in the mean value were analyzed

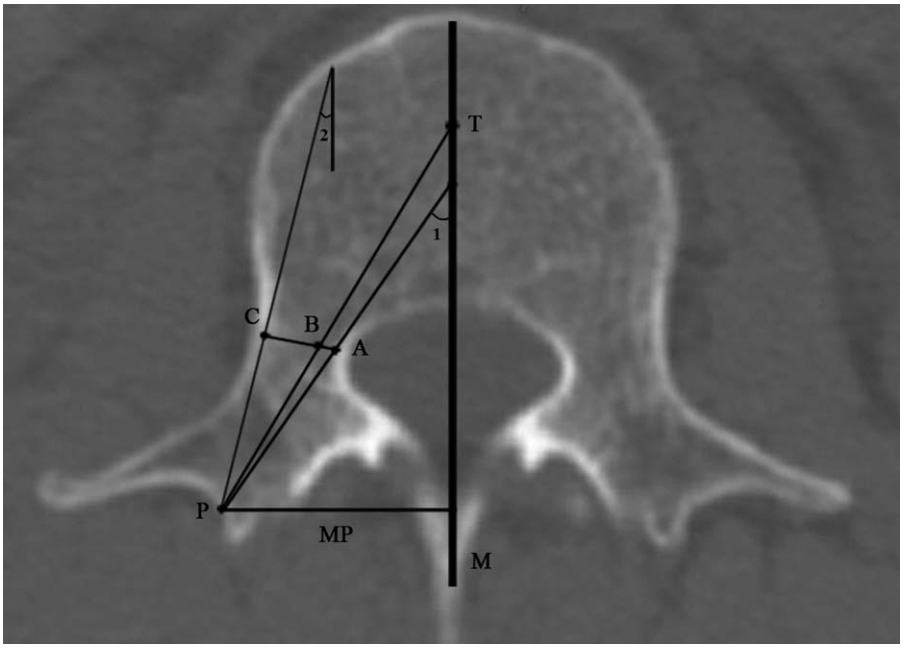

Figure 1. Measurement methods of the distance, angles, and success rates. *M* indicates the midline, *P* indicates the entry point in the CTPA which was at lateral edge of pedicle projection, *MP* indicates the vertical distance between M and P, *T* indicates the target point (at the anterior one-third of the midline), ∠1 indicates the maximum puncture inner inclination angle, ∠2 indicates the minimum puncture inner inclination, and *B* indicates the crossing point between AC and PT.

Table 1

Distance from the puncture to the midline of the vertebra (mm).

Levels	Sex		Side		Age			Mean
	Male	Female	Left	Right	50–60	60–70	≥70	
L1	21.5±1.9	19.8±1.7†	20.3±1.9	21.0±2.0†	20.4±1.9	21.0±2.0‡	21.1±2.5	20.6±2.0
L2	21.9±1.9	20.5±1.7†	20.9±1.9	21.4±2.0†	20.9±1.8	21.6±2.0‡	21.5±2.2	21.1±1.9*
L3	23.7±2.1	22.3±1.9†	22.8±2.1	23.3±2.0†	22.9±2.0	23.1±1.9	23.7±2.7‡	23.0±2.1*
L4	25.5±2.3	24.2±2.1†	24.7±2.3	24.9±2.2	24.7±2.2	25.1±2.2	25.0±2.7	24.8±2.3*
L5	30.6±2.8	29.0±2.8†	29.6±2.9	29.9±2.9	29.6±2.8	30.1±2.8	30.0±3.5	29.8±2.9*

* Significant difference compared to upper level-mean value.
† Significant difference between male and female or left and right.
‡ Significant difference compared to 50 to 60 age group.
Significant difference compared to 60 to 70 age group.

with a paired *t* test or independent *t* tests. The enumerated data were analyzed using χ^2 test. $P < .05$ was considered statistically significant.

3. Results

3.1. DEM

In the mean DEM, significant differences ($P < .05$) between different levels were shown and significant differences ($P < .05$) between the male and female for L1 to L5, left and right side for L1 to L3 were also shown. The DEM in the 60 to 70 or ≥70 age range group was significantly larger than that in 50 to 60 age range group for L1 to L3. The DEM from L1 to L5 was significantly increased ($P < .05$) from (20.6±2.0) mm to (29.8±2.9) mm (Table 1).

3.2. PIA and SRA

The maximum PIAs were significantly different between different levels ($P < .05$). For L1 to L5, the right maximum PIA was significantly larger than the left. The maximum PIA in the male was significantly larger than that in the female. The maximum PIA in 60 to 70 age range group was significantly larger than that in 50 to 60 age range group for L2 to L4. The SRA in male was significantly larger than that in female. The right SRA was significantly larger than the left for L3 and L4. The SRA in 60 to 70 age range group was significantly larger than that in 50 to 60 age range group for L1 to L5. The SRA from L1 to L5 was significantly increased ($P < .05$) from (19.5±5.9)° to (48.9±8.1)° (Table 2).

3.3. SR

The differences in the SR between each level were significant ($P < .05$). The SR in male was significantly ($P < .05$) larger than that in female for L1 to L4. There were no significant differences in the SR between right and left. There were no significant differences in the SR between different age groups except for L4. The SRs for L1 to L5 were 26.3%, 38.0%, 67.0%, 88.3%, and 99.0%. The SR from L1 to L5 was significantly increased ($P < 0.05$) from 26.3% to 99.0% (Table 3).

Table 2

Maximum, minimum, and safe range of inner inclination angles (°).

Levels	Angle	Sex		Side		Age			Mean
		Male	Female	Left	Right	50–60	60–70	≥70	
L1	Max	30.2±4.2	28.3±4.1†	28.5±4.1	29.9±4.3†	28.9±4.4	29.6±3.9	29.6±4.6	29.2±4.3
	Min	8.7±4.6	10.7±4.1†	9.3±4.2	10.2±4.7†	10.0±4.1	9.1±5.1	9.2±4.3	9.7±4.5
	SRA	21.5±6.2	17.5±4.9†	19.2±5.7	19.7±6.1	18.9±5.6	20.5±6.3‡	20.4±6.3	19.5±5.9
L2	Max	32.4±3.7	31.0±3.8†	31.1±3.6	32.3±3.9†	31.3±3.9	32.4±3.4‡	32.1±3.8	31.7±3.8*
	Min	7.9±4.6	10.1±4.2†	8.7±4.3	9.4±4.8†	9.4±4.3	8.2±5.4‡	9.0±3.1	9.0±4.6*
	SRA	24.6±6.4	20.8±5.1†	22.4±5.9	22.9±6.2	21.9±5.7	24.2±6.9‡	23.1±4.8	22.7±6.1*
L3	Max	36.5±4.2	35.5±3.8†	35.3±3.8	36.7±4.1†	35.5±3.8	36.8±4.2‡	36.8±4.3	36.0±4.0*
	Min	7.2±5.4	9.7±4.8†	8.1±5.2	8.8±5.3†	9.0±4.9	7.0±5.6‡	9.5±5.3§	8.4±5.2*
	SRA	29.4±7.1	25.8±5.9†	27.1±6.6	27.9±6.8†	26.5±6.2	29.8±7.6‡	27.3±5.7	27.5±6.7*
L4	Max	42.9±8.2	40.5±5.2†	40.7±4.4	42.6±8.7†	41.3±5.0	42.8±10. 3‡	41.9±5.6	41.6±7.0*
	Min	5.4±6.0	7.9±5.5†	6.6±6.1	6.8±5.7	7.5±5.6	5.3±6.5‡	5.7±5.3	6.7±5.9*
	SRA	37.4±10.2	32.6±7.5†	34.1±7.6	35.8±10.7†	33.8±7.7	37.0±12.0‡	36.2±8.2	34.9±9.3*
L5	Max	54.0±6.3	53.5±5.6†	52.8±5.6	54.7±6.1†	53.5±6.1	53.9±5.5	54.6±6.4	53.7±5.9*
	Min	4.5±6.6	5.1±5.8†	4.3±6.4	5.3±6.0†	5.6±5.7	3.3±6.8‡	3.7±6.7	4.8±6.2*
	SRA	49.5±8.7	48.4±7.5†	48.5±8.4	49.4±7.8	47.9±7.9	50.6±7.8‡	50.9±9.8	48.9±8.1*

* Significant difference compared to upper level-mean value.
† Significant difference between male and female or left and right.
‡ Significant difference compared to 50 to 60 age group.
§ Significant difference compared to 60 to 70 age group.

Table 3

SR of each puncture according to different sex, sides, levels, and ages.

	Sex		Side		Age			
Levels	**Male**	**Female**	**Left**	**Right**	**50–60**	**60–70**	**≥70**	**Total**
L1	81 (41.3)	24 (11.8)[†]	54 (27.0)	51 (25.5)	61 (24.6)	33 (28.9)	11 (28.9)	105 (26.3)
L2	113 (57.7)	39 (19.1)[†]	78 (39.0)	74 (37.0)	87 (35.1)	48 (42.1)	17 (44.7)	152 (38.0)[*]
L3	161 (82.1)	107 (52.5)[†]	136 (68.0)	132 (66.0)	161 (64.9)	80 (70.2)	27 (71.1)	268 (67.0)[*]
L4	182 (92.9)	171 (83.8)[†]	177 (88.5)	176 (88.0)	221 (89.1)	103 (90.4)	29 (76.3)[‡,§]	353 (88.3)[*]
L5	195 (99.5)	201 (98.5)	199 (99.5)	197 (98.5)	247 (99.6)	111 (97.4)	38 (100.0)	396 (99.0)[*]
Each	196	204	200	200	248	114	38	400

[*] Significant difference compared to upper level-total.
[†] Significant difference between male and female or left and right.
[‡] Significant difference compared to 50 to 60 age group.
[§] Significant difference compared to 60 to 70 age group.

4. Discussion

PKP using the bilateral or unilateral CTPA is the most popularly adopted method.[10–16] Many recent systemic reviews and clinical studies have showed that unilateral and bilateral PKP were both effective for the treatment of OVCFs; unilateral PKP had a shorter operation time, less radiation exposure time compared with bilateral PKP.[10–16] Because of the anatomical distinctions of unilateral CTPA is not identical in all cases. So we carried out the study to explore the significance of age, sex, level, and side in relation to the anatomical distinctions of unilateral PKP for lumbar OVCFs through the CTPA.

In the present study, the DEM from L1 to L5 was significantly increased from (20.6 ± 2.0) mm to (29.8 ± 2.9) mm. The previous study showed that the DEM gradually increased from L1 (22.0 ± 2.7) mm to L5 (30.0 ± 4.0) mm through MRI data measured from 200 patients,[16] and the DEM gradually increased from L1 (20.6 ± 2.2) mm to L5 (28.6 ± 2.9) mm through CT data measured from 30 patients.[23] Significant differences between the male and female for L1 to L5, left and right side for L1 to L3 in the mean DEM were shown; these results were consistent with previous study.[16] We think the present study maybe more persuasive because we collected CT data from 200 patients, and we can reconstruct 3D image from the CT data and make more optimal and safe puncture approach.

For L1 to L5, the right maximum PIA was significantly larger than the left. The maximum PIA and SRA in the male was significantly larger than that in the female. The SRA from L1 to L5 was significantly increased from (19.5 ± 5.9)° to (48.9 ± 8.1)°. The SR in male was significantly higher than that in female for L1 to L4. There were no significant differences in the SR between different age groups except for L4. The SR from L1 to L5 was significantly increased from 26.3% to 99.0%. Through the study, we can see that it is very important and necessary to observe the 3-dimension reconstruction and display of medical image data, carefully measure and compare different puncture approaches, choose the optimal and safe puncture approach for each individual and level.

In the present study, we take a deep analysis about the age, sex, level, and side differences especially the age groups differences in the anatomical distinctions of unilateral PKP for elderly through the CTPA, the DEM in the 60 to 70 or ≥70 age range group was significantly larger than that in 50 to 60 age range group for L1 to L3, the maximum PIA in 60 to 70 age range group was significantly larger than that in 50 to 60 age range group for L2 to L4. The SRA in 60 to 70 age range group was significantly larger than that in 50 to 60 age range group for L1 to L5. There were no significant differences in the SR between different age groups except for L4. These data will be beneficial for orthopedist to treat elderly patients of different age range groups who presented with OVCFs through the CTPA.

There are some limitations to this study. As 200 patients were included, the sample size was still relatively small. The diameters of the vertebral body, width of the pedicles, iliac crest block, operator's experience, and ancillary equipment may affect the success of unilateral puncture.

5. Conclusions

DEM was 20.6 to 29.8 mm according to different levels. The value of DEM, PIA, SRA, and SR was significantly increased from L1 to L5. No significant differences in the SR between right and left for L1 to L5, different age groups except for L4 were observed. For L1 to L3, the performance of bilateral PKP is safe and reasonable, particularly for the female. For L4 and L5, unilateral puncture is feasible and reliable, particularly for the male.

Author contributions

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Project administration: Hongwei Wang, Pan Hu, Ning Zhang, Jun Wu, Liangbi Xiang.
Resources: Pan Hu, Yu Chen.
Software: Deluo Wu.
Supervision: Yu Chen, Liangbi Xiang.
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Writing – original draft: Hongwei Wang, Pan Hu, Deluo Wu, Ning Zhang, Jun Wu, Yu Chen, Liangbi Xiang.
Writing – review and editing: Hongwei Wang, Yu Chen, Liangbi Xiang.

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