Observational Study

Medicine®

OPEN

Unilateral percutaneous kyphoplasty for lumbar spine

A comparative study between transverse process-pedicle approach and conventional transpedicular approach

Hongwei Wang, PhD[a,b,c,*], Pan Hu, MD[a,d], Weijie Xu, MD[a], Ying Feng, MD[a], Yan Zhang, MD[a], Yunpeng Zhu, MD[a], Weijian Ren, PhD[a], Liangbi Xiang, MD[a]

Abstract

Anatomical differences of unilateral percutaneous kyphoplasty (PKP) between transverse process-pedicle approach (TPPA) and conventional transpedicular approach (CTPA) are not well discussed. To investigate the anatomical distinctions of unilateral PKP between TPPA and CTPA, we have discussed the unilateral PKP through a 3-dimensional-computed tomography database.

Five hundred lumbar spines from 100 patients have been retrospectively collected and unilateral CTPA and TPPA were simulated. Distance between the entry point and the midline of the vertebral body (DEM), the puncture inclination angle (PIA), and the success rate (SR) of puncture were measured and compared.

The male presented with significantly larger DEM than the female. The TPPA group presented with larger DEM than the CTPA group according to different level, the difference was 1.5 ± 1.1 mm to 3.8 ± 2.3 mm. The PIAs in the TPPA group were larger than that in the CTPA group. The SR including 1 side SR and bilateral SR was 72.0% in the CTPA group and 98.0% in the TPPA group. Compared with CTPA group, the SR in TPPA group was significantly higher for L1 to L4 no matter in the left, right side and female patients.

The TPPA group presented with more lateral entry point, larger PIAs and higher SRs than that in the CTPA group. PKP surgery through a TPPA was safer and could provide a more symmetrical distribution of bone cement than the CTPA group.

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, RSA = range of the safe puncture angle, SR = success rate, TPPA = transverse process-pedicle approach.

Keywords: lumbar, osteoporotic vertebral compression fracture, percutaneous kyphoplasty, transverse process, unilateral

1. Introduction

Osteoporotic vertebral compression fractures (OVCFs) are frequent in elderly females, and may result in debilitating pain, spinal deformity, and severe morbidity. Percutaneous kyphoplasty (PKP) was popularly adopted to treat painful OVCFs, both unilateral and bilateral PKP provided effective and safe treatment for patients with painful OVCFs, unilateral PKP presented with less operation time, cement volume, surgery-related costs, radiation dose and lower rate of cement leakage compared with bilateral PKP.[1–11] A study showed that bilateral PKP was better than unilateral PKP in the restoration rate.[10] Although so many

Editor: Shogo Hayashi.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

HW and PH contributed equally to this work.

This work was supported by the Project Funded by China Postdoctoral Science Foundation (2020), the Liaoning Provincial Natural Science Foundation of China (2019-ZD-1032), and the Foundation of State Key Laboratory of Robotics (2017-O01).

The authors have no conflicts of interest to disclose.

[a] Department of Orthopedics, General Hospital of Northern Theater Command of Chinese PLA, [b] State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Science, Shenyang, Liaoning, [c] State Key Laboratory of Materials Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan, Hubei, [d] Department of Orthopedics, Chinese Medicine Hospital of Dianjiang County, Dianjiang, Chongqing, China.

[*] Correspondence: Hongwei Wang, Department of Orthopedics, General Hospital of Northern Theater Command of Chinese PLA, Shenyang 110016, Liaoning, China (e-mail: cplawhw@163.com).

How to cite this article: Wang H, Hu P, Xu W, Feng Y, Zhang Y, Zhu Y, Ren W, Xiang L. Unilateral percutaneous kyphoplasty for lumbar spine: a comparative study between transverse process-pedicle approach and conventional transpedicular approach. Medicine 2020;99:17(e19816).

Received: 3 December 2019 / Received in final form: 16 February 2020 / Accepted: 3 March 2020

http://dx.doi.org/10.1097/MD.0000000000019816

puncture approaches and intraoperative guidance techniques and equipments have been devised, PKP using conventional transpedicle approach (CTPA) under the C-arm is the most commonly used method.[12–23]

It has been shown that the stable biomechanics of the fractured vertebra can be achieved by unilateral PKP if the bone cement distribution exceeds the midline of the vertebral body.[16] Transverse process-pedicle approach (TPPA) has been investigated in previous studies.[21–23] Unilateral TPPA has been shown more advantages over bilateral PKP such as due to smaller cement volume and radiation dose, shorter operation time, more restoration of kyphotic angle, and less complications.[22,23] Anatomical differences of unilateral PKP between TPPA and CTPA are not well discussed. So we discuss the anatomical distinctions of unilateral PKP through a 3-dimensional-computed tomography (3D-CT) database and compare the CTPA and TPPA especially on different levels, sexes, and sides.

2. Materials and methods

2.1. Study population and measurement of data

One hundred outpatients (45 males, 55 females, age from 50 to 85 years old, mean age of 58.5 years old) who have done 3D-CT scans (GE Light Speed VCT 64-Slice CT, scan slice of 0.625 mm) of L1-L5 were collected from May 1, 2015 to December 20, 2015. Inclusion criteria were as follows: patients experienced lower back pain that could be determined with CT scans available; images must be clear with a CT scan slice of 0.625 mm. Exclusion criteria: a history of lumbar surgery vertebral abnormalities and developmental abnormalities. The distance between the entry point and the midline of the vertebral body (DEM), the puncture inclination angle (PIA), the range of the safe puncture angle (RSA), and the success rate (SR) of puncture (Fig. 1) were measured and recorded according to previous studies[21,24] on the Aquarius iNtuition workstation. 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. This study was approved by the ethics committee of General Hospital of Northern Theater Command of Chinese PLA.

2.2. Statistical analysis

Software IBM SPSS Statistics 24.0 was adopted on data analysis. Level of statistical significance was defined as P-value $<.050$. T tests were used to analyze the differences in the mean value. The enumerated data were analyzed using Chi-squared test. The data were recorded as means ± standard deviations.

3. Results

3.1. DEM

The DEM in the TPPA group was slightly larger than that in the CTPA group. There were significant differences in the mean DEM between the CTPA group and TPPA group ($P < .05$). Male presented with significantly larger DEM than female in CTPA group or TPPA group ($P < .05$) (Table 1).

3.2. PIA

The PIAs in the TPPA group were all larger than those in the CTPA group (Table 2). The maximum PIA was significantly larger in right than left. The maximum PIA was significantly larger in male than female for L1, L2, and L4 (Table 3). The RSA in TPPA group was significantly larger than that in CTPA group for L1 and L4, but opposite for L5.

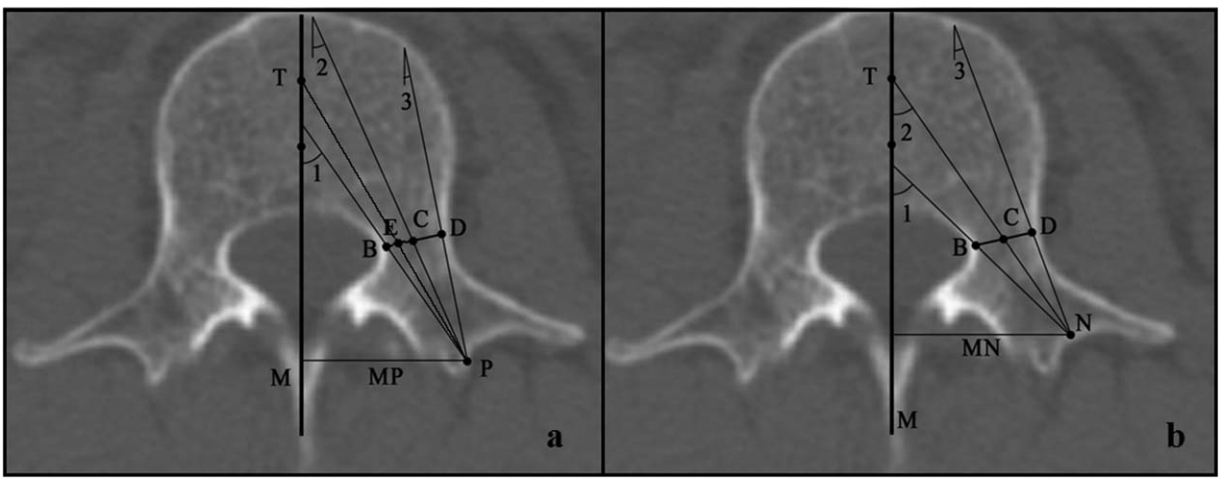

Figure 1. Measurement methods of the distance, angles and success rates. (A) CTPA group. (B) TPPA group. M indicates the midline, P indicates the entry point in the CTPA which was at lateral edge of pedicle projection, N indicates the entry point in the TPPA which was defined as the crossing point between the puncture course and the transverse process. MP indicates the vertical distance between M and P, MN indicates the vertical distance between M and N, DEM means MP or MN, T indicates the target point (at the anterior one-third of the midline), ∠1 indicates the maximum puncture inner inclination angle, ∠2 indicates the middle puncture inner inclination angle, ∠3 indicates the minimum puncture inner inclination, B indicates the medial cortical points of the narrowest pedicle, D indicates the lateral cortical points of the narrowest pedicle, C indicates the midpoint of BD, E indicates the crossing point between BD and PT. If BE in CTPA or BC in TPPA was more than 2 mm, the puncture would achieve success, if not, the puncture would fail certainly. CTPA = conventional transpedicle approach, DEM = distance between the entry point and the midline of the vertebral body, TPPA = transverse process-pedicle approach.

Table 1

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

	DEM- CTPA					DEM- TPPA					ΔDEM				
Distance	Left	Right	Female	Male	Mean	Left	Right	Female	Male	Mean	Left	Right	Female	Male	Mean
L1	20.4±2.0	21.2±2.1‡	20.0±1.9	21.8±1.9*	20.8±2.1	21.9±2.0	22.8±2.0‡	21.6±1.8	23.2±2.0*	22.3±2.0§	1.4±1.1	1.6±1.1	1.6±1.2	1.4±1.0	1.5±1.1
L2	21.0±1.8	21.6±2.0‡	20.6±1.6	22.0±1.9*	21.3±1.9†	22.4±1.8	23.4±2.0‡	22.4±1.7	23.6±2.0*	22.9±1.9†,§	1.5±0.9	1.8±1.0‡	1.7±1.0	1.5±1.0	1.6±1.0
L3	23.1±2.2	23.7±2.3‡	22.8±2.1	24.1±2.1*	23.4±2.2†	24.7±2.1	25.5±2.1‡	24.5±2.0	25.8±2.1*	25.1±2.1†,§	1.6±1.0	1.8±1.3	1.7±1.2	1.7±1.1	1.7±1.2
L4	24.9±2.4	25.1±2.4	24.4±2.3	25.7±2.3*	25.0±2.4†	26.3±2.5	27.1±2.4‡	26.0±2.3	27.5±2.4*	26.7±2.5†,§	1.4±0.8	2.0±1.2‡	1.6±1.0	1.7±1.1	1.7±1.1
L5	29.7±3.1	30.2±2.9‡	29.1±2.8	31.0±2.8*	30.0±3.0†	32.9±3.9	34.6±4.5‡	33.0±4.5	34.7±3.8*	33.7±4.3†,§	3.2±1.9	4.4±2.5‡	3.9±2.5	3.6±2.0	3.8±2.3†

CTPA = conventional transpedicle approach, DEM = distance between the entry point and the midline of the vertebral body, TPPA = transverse process-pedicle approach.

* Significant difference between the male and the female.

† Significant difference compared to upper level-mean value.

‡ Significant difference between the left and right.

§ Significant difference between the CTPA and TPPA-mean value.

Table 2

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

		CTPA					TPPA				
Lumbar vertebra	Angle	Left	Right	Female	Male	Mean	Left	Right	Female	Male	Mean
L1	Max	29.3±3.9	30.7±4.0‡	28.9±3.9	31.4±3.7*	30.0±4.0	35.7±3.8	38.5±3.6‡	36.2±3.9	38.2±3.7*	37.1±4.0§
	Min	10.3±4.0	11.5±4.3‡	11.5±4.1	10.2±4.3*	10.9±4.2	15.9±3.9	18.7±3.7‡	18.3±3.8	16.1±4.0*	17.3±4.0§
	SRA	19.0±5.4	19.2±5.7	17.4±4.9	21.2±5.6*	19.1±5.6	19.7±6.2	19.8±5.9	17.8±5.5	22.1±5.9*	19.7±6.0§
L2	Max	31.7±3.5	33.3±4.0‡	31.7±3.7	33.5±3.7*	32.5±3.8†	37.4±3.4	40.3±3.9‡	38.3±3.7	39.6±4.0*	38.9±3.9†,§
	Min	9.9±4.3	10.7±4.2	11.2±4.5	9.2±3.7*	10.3±4.3	15.4±4.1	18.1±3.6‡	17.9±3.9	15.2±3.9*	16.7±4.1§
	SRA	21.8±5.6	22.6±6.1	20.6±5.5	24.2±5.6*	22.2±5.8†	22.0±6.5	22.3±6.0	20.3±5.7	24.4±6.2*	22.1±6.2†
L3	Max	35.9±4.1	37.5±4.4‡	36.2±4.0	37.3±4.6	36.7±4.3†	41.6±4.3	44.9±4.5‡	42.9±4.6	43.7±4.8	43.2±4.7†,§
	Min	10.1±4.5	10.9±4.9	11.2±5.2	9.6±4.0*	10.5±4.7	15.9±4.3	18.2±4.4‡	18.0±4.3	15.9±4.4*	17.0±4.5§
	SRA	25.8±6.2	26.7±6.8‡	25.1±6.2	27.7±6.6*	26.2±6.5†	25.7±7.2	26.7±7.4‡	24.9±6.7	27.8±7.6*	26.2±7.3†
L4	Max	41.4±5.0	43.0±5.5‡	41.2±5.4	43.4±4.9*	42.2±5.3†	48.8±4.4	52.4±4.5‡	49.8±5.2	51.6±4.1*	50.6±4.8†,§
	Min	8.3±5.3	8.6±5.0	9.3±5.2	7.5±4.9*	8.5±5.1†	14.3±5.7	17.1±5.0‡	16.5±5.5	14.7±5.4*	15.7±5.5†,§
	SRA	33.1±7.4	34.4±7.2‡	31.9±7.2	36.0±6.9*	33.7±7.3†	34.5±8.0	35.3±7.5	33.3±7.7	36.9±7.3*	34.9±7.7†,§
L5	Max	54.0±5.9	56.2±6.6‡	53.5±5.8	57.0±6.6*	55.1±6.4†	61.0±4.7	66.3±4.6‡	63.1±5.6	64.4±5.0	63.7±5.4†,§
	Min	6.1±5.7	8.1±5.1‡	6.9±5.7	7.3±5.2	7.1±5.5†	17.3±6.7	22.7±7.5‡	20.6±7.5	19.3±7.6	20.0±7.6†,§
	SRA	47.9±8.3	48.1±7.4	46.7±7.4	49.7±8.0*	48.0±7.8†	43.7±8.7	43.5±8.4	42.4±7.9	45.1±9.0*	43.6±8.5†,§

CTPA = conventional transpedicle approach, TPPA = transverse process-pedicle approach.

* Significant difference between the male and the female.

† Significant difference compared to upper level-mean value.

‡ Significant difference between the left and right.

§ Significant difference between the CTPA and TPPA-mean value.

3.3. SR

The SR was lower in the CTPA group than the TPPA group. The SR including 1 side SR and bilateral SR was 72.0% in the CTPA group and 98.0% in the TPPA group (Table 3). The bilateral SR for L1 to L5 were 25.0%, 35.0%, 65.0%, 81.0%, 94.0% in CTPA group and 84.0%, 90.0%, 99.0%, 100.0%, 100.0% in TPPA group. The 1 side SR for L1 to L5 were 14.0%, 18.0%, 12.0%, 11.0%, 5.0% in CTPA group and 8.0%, 8.0%, 1.0%,0%, 0% in TPPA group. There were significant differences in the bilateral and 1 side SR among the different lumbar segments except for L5 ($P < .01$). There were no significant differences in the SR between the left and right sides at each vertebral level. The SR in male was significantly higher than that in female for L1 to L3 in the CTPA group and L1 in the TPPA group (Table 4).

4. Discussion

PKP for OVCFs could be divided into unilateral and bilateral pedicular approaches, extrapedicular approaches and TPPAs.[15,21–31] Until now, there is still no consensus about the optimal approach, but unilateral approaches have been gradually accepted because of less operation time, cement volume, radiation dose of patients, cement leakage, and surgery-related costs.[25–27] TPPAs have been investigated in previous studies.[21–23] Compared with the bilateral transpedicular technique, unilateral TPPA seems to have more advantages such as smaller radiation dose, shorter operation time, more restoration of kyphotic angle, and less complications.[22,23] Evaluation of intraoperative and postoperative radiographs revealed extravertebral cement leakages in 7.6% patients (12/158) treated by unilateral transverse process-pedicle technique and in 14.6% patients (22/151) treated using bilateral transpedicular technique.[22] The high rate of extravertebral cement leakages may be related to fracture patterns, surgical technique, and anatomy of the vertebral bodies. To investigate the anatomical distinctions of unilateral PKP between TPPA and CTPA, we have discussed the unilateral PKP through a 3D-CT database.

The optimal target location of unilateral PKP surgery was 1/3 anterior and middle region of the vertebral body as well as bone cement can diffuse to the contralateral side, which could obtain

Table 3

SR according to different levels.

	L1		L2		L3		L4		L5	
Group	Success (O/B)	Failure	Success (O/B)	Failure	Success (O/B)	Failure	Success (O/B)	Failure	Success (O/B)	Failure
CTPA	39 (14/25)	61	53 (18/35)*	47	77 (12/65)*	23	92 (11/81)*	8	99 (5/94)*	1
TPPA	92 (8/84)	8	98 (8/90)	2	100 (1/99)	0	100 (0/100)	0	100 (0/100)	0
P, t-S/F	$P<.01$, $t=62.153$		$P<.01$, $t=54.737$		$P<.01$, $t=25.989$		$P=.012$, $t=6.380$		$P=1.000$, $t=0.000$	
P, t-O/B	$P<.01$, $t=14.503$		$P<.01$, $t=16.062$		$P<.01$, $t=13.597$		$P<.01$, $t=12.683$		$P=.068$, $t=3.324$	

CTPA = conventional transpedicle approach, O/B = one side/bilateral success, SR = success rate, TPPA = transverse process-pedicle approach.
* Significant difference compared to upper level.

Table 4

SR according to different levels, sides, and genders.

	CTPA				TPPA			
Group	Left	Right	Female	Male	Left	Right	Female	Male
L1	34/100	31/100	12/55	27/45*	87/100‡	89/100‡	47/55‡	45/45*,‡
L2	44/100	43/100	18/55	34/45*	92/100‡	96/100‡	53/55‡	45/45‡
L3	72/100	68/100	37/55	40/45*	99/100‡	100/100‡	55/55‡	45/45
L4	87/100	84/100	49/55	43/45	100/100‡	100/100‡	55/55‡	45/45
L5	99/100	97/100	54/55	45/45	100/100	100/100	55/55	45/45

CTPA = conventional transpedicle approach, SR = success rate, TPPA = transverse process-pedicle approach.
* Significant difference between the male and the female.
‡ Significant difference between the CTPA and TPPA.

the same satisfactory clinical outcome as bilateral approach PKP.[31] In practice, accurate location of the osseous insertion site of the needle is important, and if the position deviates, puncture needle cannot reach the target site and easily break the inner wall of the pedicle resulting in spinal cord or nerve damage. Unilateral pedicular PKP guided by preoperative CT image data is effective, convenient and safe with high puncture accuracy, shorter time and less radiation exposure in treatment of thoracic and lumbar OVCFs.[31]

In the present study, the entry point of the TPPA is localized at about 1.5 to 3.8 mm outside the lateral margin of the pedicle projection. The mean DEM and PIA were significantly larger from L1 to L5 in TPPA than CTPA. The mean DEM were significantly larger from L1 to L5 in male than female patients no matter in CTPA and TPPA. The mean safe range of male patients was wider than female patients no matter in the TPPA and CTPA group. The SR of lumbar unilateral PKP is closely associated with the vertebral segment, patient sex, and left or right location. The SR of puncture via a TPPA was significantly higher than that via the CTPA except for L5. The CTPA group presented with significantly higher only 1 side SR than the TPPA group. Given these findings, we present the following suggestions: for L1 to L4, it is reasonable and safe to select unilateral TPPA. The safe range of the TPPA was wider than CTPA in L1, L4, and L5. The mean safe range of male patients was wider than female patients no matter in the TPPA and CTPA group. It is very important and necessary to carefully measure and compare the imaging data before choosing the optimal puncture approach for each individual and level.

There are some limitations. The number of the cases was relatively small and there is discrepancy in terms of sex and age between the population investigated in this study and patients (elderly women) with OVCF. There is some controversy about the definition of the target point.

5. Conclusions

The TPPA group presented with more lateral entry point than that in the CTPA group according to different levels. Compared with CTPA, the PIA in the TPPA was much larger with a high SR. The mean RSA of male patients was wider than female patients no matter in the TPPA and CTPA group. It is very important and necessary to carefully measure and compare the imaging data before choosing the optimal puncture approach for each individual and level.

Author contributions

Data curation: Pan Hu, Weijian Ren.
Formal analysis: Pan Hu, Weijie Xu, Ying Feng, Yan Zhang, Yunpeng Zhu, Weijian Ren, Liangbi Xiang.
Methodology: Weijie Xu, Ying Feng, Yan Zhang, Yunpeng Zhu.
Software: Pan Hu.
Supervision: Liangbi Xiang.
Validation: Pan Hu.
Visualization: Liangbi Xiang.
Writing – original draft: Pan Hu, Weijie Xu, Ying Feng, Yan Zhang, Yunpeng Zhu, Weijian Ren.
Writing – review and editing: Liangbi Xiang.
Hongwei Wang orcid: 0000-0002-2367-3465.

References

[1] Wardlaw D, Cummings SR, Van Meirhaeghe J, et al. Efficacy and safety of balloon kyphoplasty compared with non-surgical care for vertebral compression fracture (FREE): a randomised controlled trial. Lancet 2009;373:1016–24.
[2] Cohen D. Balloon kyphoplasty was effective and safe for vertebral compression fractures compared with nonsurgical care. J Bone Joint Surg Am 2009;91:2747.
[3] Bae H, Shen M, Maurer P, et al. Clinical experience using Cortoss for treating vertebral compression fractures with vertebroplasty and

kyphoplasty: twenty four-month follow-up. Spine (Phila Pa 1976) 2010;35:E1030–6.
[4] Boonen S, Van Meirhaeghe J, Bastian L, et al. Balloon kyphoplasty for the treatment of acute vertebral compression fractures: 2-year results from a randomized trial. J Bone Miner Res 2011;26:1627–37.
[5] Van Meirhaeghe J, Bastian L, Boonen S, et al. A randomized trial of balloon kyphoplasty and non-surgical management for treating acute vertebral compression fractures: vertebral body kyphosis correction and surgical parameters. Spine (Phila Pa 1976) 2013;38:971–83.
[6] Chang X, Lv YF, Chen B, et al. Vertebroplasty versus kyphoplasty in osteoporotic vertebral compression fracture: a meta-analysis of prospective comparative studies. Int Orthop 2015;39:491–500.
[7] Wang H, Sribastav SS, Ye F, et al. Comparison of percutaneous vertebroplasty and balloon kyphoplasty for the treatment of single level vertebral compression fractures: a meta-analysis of the literature. Pain Physician 2015;18:209–22.
[8] Zhao S, Xu CY, Zhu AR, et al. Comparison of the efficacy and safety of 3 treatments for patients with osteoporotic vertebral compression fractures: a network meta-analysis. Medicine (Baltimore) 2017;96: e7328.
[9] Sun H, Lu PP, Liu YJ, et al. Can unilateral kyphoplasty replace bilateral kyphoplasty in treatment of osteoporotic vertebral compression fractures? A systematic review and meta-analysis. Pain Physician 2016;19:551–63.
[10] Cheng X, Long HQ, Xu JH, et al. Comparison of unilateral versus bilateral percutaneous kyphoplasty for the treatment of patients with osteoporosis vertebral compression fracture (OVCF): a systematic review and meta-analysis. Eur Spine J 2016;25:3439–49.
[11] Chang W, Zhang X, Jiao N, et al. Unilateral versus bilateral percutaneous kyphoplasty for osteoporotic vertebral compression fractures: a meta-analysis. Medicine (Baltimore) 2017;96:e6738.
[12] Papadopoulos EC, Edobor-Osula F, Gardner MJ, et al. Unipedicular balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures: early results. J Spinal Disord Tech 2008; 21:589–96.
[13] Song BK, Eun JP, Oh YM. Clinical and radiological comparison of unipedicular versus bipedicular balloon kyphoplasty for the treatment of vertebral compression fractures. Osteoporos Int 2009;20:1717–23.
[14] Yang XM, Wu TL, Xu HG, et al. Modified unilateral transpedicular percutaneous vertebroplasty for treatment of osteoporotic vertebral compression fractures. Orthop Surg 2011;3:247–52.
[15] Chen B, Li Y, Xie D, et al. Comparison of unipedicular and bipedicular kyphoplasty on the stiffness and biomechanical balance of compression fractured vertebrae. Eur Spine J 2011;20:1272–80.
[16] Chen L, Yang H, Tang T. Unilateral versus bilateral balloon kyphoplasty for multilevel osteoporotic vertebral compression fractures: a prospective study. Spine (Phila Pa 1976) 2011;36:534–40.
[17] Wang Z, Wang G, Yang H. Comparison of unilateral versus bilateral balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures. J Clin Neurosci 2012;19:723–6.
[18] Zhang L, Liu Z, Wang J, et al. Unipedicular versus bipedicular percutaneous vertebroplasty for osteoporotic vertebral compression fractures: a prospective randomized study. BMC Musculoskelet Disord 2015;16:145.
[19] Li H, Yang L, Tang J, et al. An MRI-based feasibility study of unilateral percutaneous vertebroplasty. BMC Musculoskelet Disord 2015;16:162.
[20] Kobayashi K, Takizawa K, Koyama M, et al. Unilateral transpedicular percutaneous vertebroplasty using puncture simulation. Radiat Med 2006;24:187–94.
[21] Wang S, Wang Q, Kang J, et al. An imaging anatomical study on percutaneous kyphoplasty for lumbar via a unilateral transverse process-pedicle approach. Spine (Phila Pa 1976) 2014;39:701–6.
[22] Yan L, Jiang R, He B, et al. A comparison between unilateral transverse process-pedicle and bilateral puncture techniques in percutaneous kyphoplasty. Spine (Phila Pa 1976) 2014;39:B19–26.
[23] Yan L, He B, Guo H, et al. The prospective self-controlled study of unilateral transverse process-pedicle and bilateral puncture techniques in percutaneous kyphoplasty. Osteoporos Int 2016;27:1849–55.
[24] Wang H, Hu P, Wu D, et al. Anatomical feasibility study of unilateral percutaneous kyphoplasty for lumbar through the conventional transpedicular approach: an observational study using 3D CT analysis. Medicine (Baltimore) 2018;97:e12314.
[25] Liu MX, Xia L, Zhong J, et al. Is it necessary to approach the compressed vertebra bilaterally during the process of PKP? J Spinal Cord Med 2020;43:201–5.
[26] Yin P, Ji Q, Wang Y, et al. Percutaneous kyphoplasty for osteoporotic vertebral compression fractures via unilateral versus bilateral approach: a meta-analysis. J Clin Neurosci 2019;59:146–54.
[27] Chen W, Xie W, Xiao Z, et al. Incidence of cement leakage between unilateral and bilateral percutaneous vertebral augmentation for osteoporotic vertebral compression fractures: a meta-analysis of randomized controlled trials. World Neurosurg 2019;122:342–8.
[28] Erkan S, Wu C, Mehbod AA, et al. Biomechanical comparison of transpedicular versus extrapedicular vertebroplasty using polymethylmethacrylate. J Spinal Disord Tech 2010;23:180–5.
[29] Ge Z, Ma R, Chen Z, et al. Uniextrapedicular kyphoplasty for the treatment of thoracic osteoporotic vertebral fractures. Orthopedics 2013;36:e1020–4.
[30] Piao M, Darwono AB, Zhu K, et al. Extrapendicular approach of unilateral percutaneous vesselplasty for the treatment of Kummell disease. Int J Spine Surg 2019;13:199–204.
[31] Zhai W, Jia Y, Wang J, et al. The clinical application and efficacy of percutaneous kyphoplasty via unilateral pedicular approach guided by CT image measurement. Int J Clin Exp Med 2015;8:20861–8.