ORIGINAL ARTICLE

Predictability of the preoperative lateral fulcrum radiograph of success in one-level vertebroplasty to treat painful osteoporotic vertebral fracture

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Abstract

Background: Restoration of height or angle has been reported following vertebroplasty (VP). The purpose of the study was to investigate the predictive value of the preoperative lateral fulcrum radiograph (LFR) of success in one-level VP for painful osteoporotic vertebral fracture.

Methods: From January 2017 to January 2018, 71 patients (mean age, 76 years) receiving VP were retrospectively analyzed. Painful vertebra was defined as pseudarthrosis or edematous change in magnetic resonance imaging (MRI) scan. Fulcrum flexibility (FF) and fulcrum restoration index (FRI) of the vertebral wedge angle (VWA), regional kyphotic angle (RKA), and anterior vertebral body height (AVBH) were investigated. Back pain was evaluated using a visual analogue scale.

Results: The 30 males and 41 females were followed for an average of 21 months. The sensitivity of LFR and MRI to detect pseudarthrosis was 92% and 97%, respectively. Preoperative FF of VWA, RKA, and AVBH was 52.4%, 58.3%, and 60%, respectively, indicating similar potential restoration ability. Postoperative average FRI for VWA, RKA, and AVBH was 1.29 ± 2.98, 0.46 ± 1.16, and 1.04 ± 1.68, respectively. Final average FRI was 0.94 ± 2.96, −0.03 ± 2.25, and 0.6 ± 2.04, respectively. VWA and AVBH had better immediate restoration, and VWA had better final maintenance. All parameters progressive lost significant levels of restoration to similar degrees but without increase in back pain.

Conclusion: LFR can help with evaluation for pseudarthrosis and the restoration effect of VP. VP had better immediate restoration of VWA and AVBH and better final VWA maintenance.

Keywords: Back pain; Humans; Pseudarthrosis; Spine; Vertebroplasty

1. INTRODUCTION

Osteoporosis with subsequent vertebral fractures is a worldwide problem.[1] Conservative treatments, including bed rest, activity restriction, brace orthosis, and medication, can be applied to symptomatic patients with vertebral fractures.[2,3] However, some patients with nonunion or intervertebral pseudarthrosis of the fractured vertebra may be refractory to conservative treatment and experience persistent back pain and progressive kyphosis,[4,5] even with appropriate conservative treatment.

Patients with intervertebral pseudarthrosis often experience dynamic instability, defined as a painful vertebra that needs aggressive therapy. Vertebroplasty (VP) for intervertebral pseudarthrosis can provide pain relief and mechanical stabilization via injection of bone cement into the void cavity.[5,6]

VP might restore 7[7] or 8.41[8] or 8.48[9] or 2.5 mm[10] of the anterior vertebral body height (AVBH) and 8.5[7] or 40%[8] or 10.6[9] of the kyphotic angle as compared to pretreated status. However, osteoporosis-related progressive kyphosis in the geriatric population is inevitably observed.[11,12] Sarcopenia,[13] or age-related disc height change,[14] and age-related collapse of the vertebral body[14] may also play a role in kyphosis progression in this population. Moreover, some authors have noted dynamic mobility of fractured vertebra in the sitting dynamic view[8] or lying stress views.[9] However, the authors did not correlate these measured parameters between the preoperative dynamic or stress views and serial postoperative changes at different follow-up occasions.

It remains speculative whether the preoperative lateral fulcrum radiograph (LFR) possesses any clinical predictive utility in the context of one-level VP for painful osteoporotic vertebral fractures. We hypothesized that LFR may simulate or predict the restoration effect for fractured vertebrae following VP. The objective of this study was to investigate the clinical significance and predictive utility of LFR for different radiographic parameters following VP in one-level painful vertebral osteoporotic fracture.

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2. METHODS

2.1. Subjects

This retrospective study was approved by the institutional review board of our hospital. The indication for percutaneous VP was painful osteoporotic vertebral fracture refractory to conservative treatment with severe local tenderness at the fractured vertebra and without leg pain.

Between January 2017 and January 2018, 98 consecutive patients diagnosed with compression or burst vertebral fractures of the thoracic or lumbar spine were treated with VP at our institute. All patients were diagnosed as having painful vertebra based on the following criteria: (1) magnetic resonance imaging (MRI) showing vertebral marrow edema in the T2-weighted image or short-TI inversion recovery views and/or (2) air accumulation or vacuum phenomenon or pseudarthrosis observed on the MRI scan.

The exclusion criteria for this study were the following: (1) diagnosis of metastasis, benign or malignant tumor, or vertebral osteomyelitis; (2) prior spinal surgery; (3) incomplete radiologic examinations or follow-up time of less than 1 year; (4) patient lost to follow-up; (5) canal compromised with neurologic deficit; or (6) patients undergoing more than two levels for index VP.

A total of 27 patients were excluded from the study: three undergoing prior spinal surgery, five had incomplete radiologic examinations, nine were lost follow-up, four had canal compromised with neurologic deficit, one died unrelated to the VP procedure, and five had multiple levels of index VP. Finally, 71 patients (30 male and 41 female) were retrospectively enrolled in the present study.

All patients underwent LFRs with a bolster placed beneath the fractured level in the supine position before the index VP. The diameter of the bolster was 16 cm. The core of the bolster was made of semirigid styrofoam 14 cm in diameter, and the surrounding material was soft sponge of 2 cm in width. The technique for making LFR is shown in Fig. 1.

2.2. Surgical technique

All VPs were performed by the same experienced surgeon (Chien-Lin Liu). A standard unilateral transpedicular approach was used to perform VP under fluoroscopic guidance and local anesthesia.[15] Postural restoration was done with two soft and radiolucent frames at the chest and anterior iliac crest area, and the patient was kept in lordosis as much as possible in the prone position. A cement gun, T-shaped injection needle, and K wires were used for VP.[16]

For patients' safety, the surgeon always stopped cement injection when there was cement leakage into either the anterior vertebral body or the disc level or leakage at the posterior one-fourth of the vertebral body. One package of polymethylmethacrylate (PMMA) cement powder (Cohesion; Vexim SA, Balma, France) was prepared and mixed with cement solution, and the result was placed into one 10-mL syringe in the liquid phase. The syringes were put into the cement gun.[16] The optimal time of the injection was during the toothpaste-like phase of cement hardening. After VP, brace protection was recommended for at least three months and ambulation encouraged with orthosis. A Taylor brace was recommended for spines with fractures at a level above L2 and T and chairback orthosis for spines with a fracture level below L2. According to the recommendation of the World Health Organization, a T score less than −2.5 was defined as osteoporosis, using dual-energy X-ray absorptiometry (DXA) of the hip.[17] All patients with osteoporosis and serum creatinine <1.6 mg/dL were prescribed intravenous bisphosphonate annually or subcutaneous denosumab for osteoporosis treatment every six months after the operation, based on the individual surgeon's decisions.

2.3. Medical records and radiographic measurements

Medical records were reviewed for patients' demographic data such as age, sex, medical history, level of fracture, follow-up duration, and bone mineral density. The fractured levels were categorized into thoracic, thoracolumbar junction, and lumbar spines. The anatomic location at the thoracolumbar junction was defined as between the T10 and L2 levels. The volume of PMMA cement injected was also recorded. Functional outcomes regarding back pain were evaluated using a visual analogue scale (VAS) for back pain on three occasions: preoperative, postoperative and at the final follow-up.

Serial supine anteroposterior and lateral radiographs were made immediately postoperatively and postoperatively at six weeks, three months, six months, twelve months, and then annually thereafter. Radiographic parameters for the vertebral wedge

Fig. 1 Illustration of a patient receiving a lateral fulcrum radiograph. The patient is placed in the supine position with a bolster placed beneath the fractured location to produce hyperextension. The diameter of the bolster is 16 cm. The rigid core of the bolster, made of styrofoam, is 14 cm in diameter, and the surrounding foam area is 2 cm wide.

angle (VWA) and regional kyphotic angle (RKA) at the fractured vertebra were measured by Cobb's method[18] (Fig. 2A, B). The negative value was defined as kyphosis in the VWA and RKA parameters. The AVBH was measured as adopted by Mumford et al[19] (Fig. 2C). Fulcrum flexibility (FF), restoration rate (RR), fulcrum restoration index (FRI), and loss RR were measured for each of the parameter regarding VWA, RKA, and AVBH.

To illustrate, the following formulas were applied in our study:

$$\text{FF }(\%) = \frac{(\text{PreVP fulcrum view parameter} - \text{PreVP parameter})}{\text{PreVP parameter}} \times 100\%$$

$$\text{RR }(\%) = \frac{(\text{PostVP parameter} - \text{PreVP parameter})}{\text{PreVP parameter}} \times 100\%$$

$$\text{FRI} = \frac{\text{RR}}{\text{Pre} - \text{VP FF}} \times 100\%$$

$$\text{Loss RR }(\%) = \frac{\text{Final parameter} - \text{PostVP parameter}}{\text{PostVP parameter}} \times 100\%$$

Radiographic measurements were performed using the PACS system (Smart Viewer 3.2; Taiwan Electronic Data Processing Cooperation, Taipei, Taiwan) by the same author (Y.-C.C.) who was not involved in the surgery, to provide an objective evaluation of the radiographs and minimize measurement bias.[20] We conducted a preliminary study to test intraobserver reliability on three occasions separated by a one- to two-week interval for these three radiographic measurements in 10 patients who were not involved in our study.

2.4. Statistical analysis

Descriptive statistical analysis was performed on the data set. Simple linear regression was utilized to investigate the correlation between two continuous parameters intragroup (i.e., age, DXA, cement volume, radiographic parameters). One-way repeated-measures ANOVA was used to determine the correlation between time and serial radiographic parameters. Then, paired-samples *t* tests were done to assess intragroup differences (i.e., comparisons of pre- and postoperative VWA). The intraclass correlation coefficient (ICC) was used to evaluate the intraobserver reliability for the preliminary measurements. Statistical analysis was performed with the SPSS for Windows statistical package, version 22.0 (IBM Corp, Armonk, NY, USA). The level of significance was established at $p < 0.05$.

3. RESULTS

The mean age at the time for VP was 76 ± 13 years (range, 60–93 years). The average time from injury to VP was 61 ± 18 days (range, 47–82 days). The location of the pathologic lesion was at the thoracolumbar junction (T10-L2) in 62 subjects and at the nonthoracolumbar junction in 9 subjects (Table 1).

The VAS for back pain statistically improved from 7 ± 1.14 (range, 5–9) preoperatively to 2 ± 0.76 (range, 1–4) after VP and was finally maintained at 2.2 ± 0.63 (range, 1–4). The mean injected cement volume for VP was 4.2 ± 1.8 mL (range, 1.5–10) with a mean 21 ± 3.5 months of follow-up (range, 13–28; Table 1). Back pain significantly improved after VP ($p < 0.0001$), and this improvement persisted until the final follow-up.

The ICC ranged from 0.917 to 0.98 in preliminary measurements by the same author (Y.-C.C.), which revealed good intraobserver reliability. The incidence of preoperative radiographic pseudarthrosis was 69% (49/71) on the plain radiographs and 92% (65/71) and 97% (69/71) on the LFR and MRI scan, respectively (Table 1). Compared to plain radiographs, LFR detected pseudarthrosis in 16 (23%) more patients. The sensitivity of LFR and MRI scan was 92% and 97%, respectively. In terms of radiographic evidence of pseudarthrosis, LFR had a similar detection

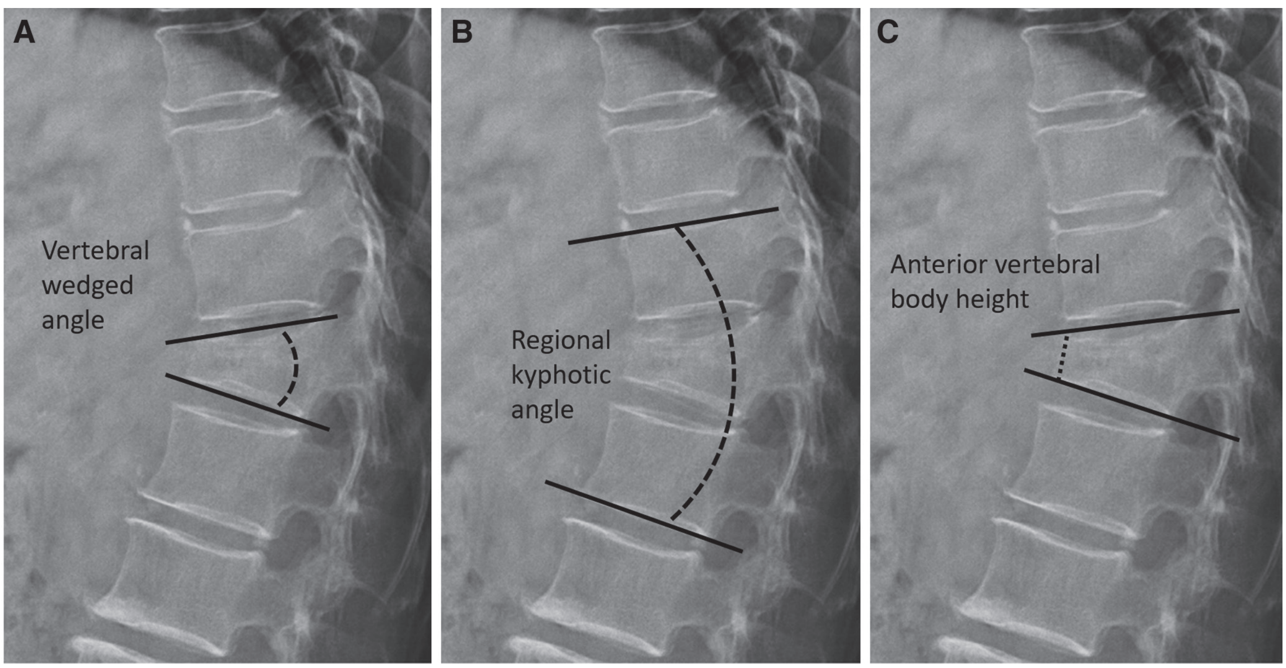

Fig. 2 Radiographic parameters for analysis. A, Vertebral wedge angle. B, Regional kyphotic angle. C, Anterior vertebral body height.

Table 1

Basic characteristics of enrolled patients (n = 71)

Age, years; mean (range)	76 ± 13 (60–93)
Gender	
Male	30
Female	41
Follow-up time, months	21 ± 3.5 (13 to 28)
Days from injury to VP	61 ± 18 (47 to 82)
DXA	−2.7 ± 0.9 (−2.6 to −4.5)
Cement volume, mL	4.2 ± 1.8 (1.5 to 10)
Pre-VP VAS at back	7 ± 1.14 (5 to 9)
Post-VP VAS at back	2 ± 0.76 (1 to 4)
Final VAS at back	2.2 ± 0.63 (1 to 3)
Diagnosis	
Osteoporotic compression fracture	47
Osteoporotic burst fracture	24
Location of lesion	
Thoracic	2 (2.8%)
Thoracolumbar junction (T10-L2)	62 (87.3%)
Lumbar	7 (9.8%)
Existence of pseudarthrosis in radiographs	
Plain film	49 (69%)
Lateral fulcrum radiograph	65 (92%)
MRI scan	69 (97%)

Data were presented as mean (minimum to maximum) or number of patients.
DXA = dual-energy x-ray absorptiometry; MRI = magnetic resonance imaging; VAS = visual analogue scale; VP = vertebroplasty.

ability as MRI scan. Representative serial plain radiographs of spines in one enrolled patient are shown in Fig. 3.

Regarding VWA, RKA, and AVBH, the serial changes at different follow-up points are shown in Table 2. These radiographic parameters changed significantly over time ($p < 0.05$), indicating progressive kyphosis and decreased AVBH following VP (Fig. 4A, B).

Regarding the VWA, the average FF was 52.4 ± 26% (range, 5%–100%), indicating the fractured vertebrae had a potential average of 52.4% more angle expansion than that predicted by preoperative LFR. The average postoperative and final FRI of VWA were 1.29 ± 2.98 (range, −2 to 17) and 0.94 ± 2.96 (range, −3.5 to 17), respectively (Table 3). The results indicated VP restored more than 29% of VWA as predicted by preoperative LFR and maintained 94% restoration of VWA at the last follow-up.

In terms of RKA, the mean FF was 58% ± 64% (range, −120% to 260%), indicating that the fractured vertebrae could have potentially an average of 58% more angle expansion than that predicted by preoperative LFR. The average postoperative and final FRI of RKA were 0.46 ± 1.16 (range, −2 to 5) and −0.03 ± 2.25 (range, −6 to 9), respectively (Table 3). In other words, VP achieved only 46% restoration of RKA postoperatively, and almost all of this restoration was ultimately lost.

The average FF of AVBH was 60 ± 47% (range, −14% to 165%), indicating the fractured vertebrae could have as much as 60% of the height restoration predicted by the preoperative LFR. The postoperative and final FRI of AVBH were 1.04 ± 1.68 (range, −0.7 to 9.5) and 0.6 ± 2.04 (range, −1.05 to 11.8; Table 3), respectively. The results indicated VP restored almost 100% of AVBH, with 60% of AVBH being maintained by the last follow-up, based on preoperative LFR.

The preoperative average FF for VWA, RKA, and AVBH were 52.4%, 58%, and 60%, respectively, indicating similar potential restoration capacity as predicted by LFR. The postoperative average FRI for VWA, RKA, and AVBH were 1.29, 0.46, and 1.04, respectively, which indicated that VP could better restore VWA and AVBH than RKA. Based on the final FRI, VWA had the best final maintenance following VP. However, the average

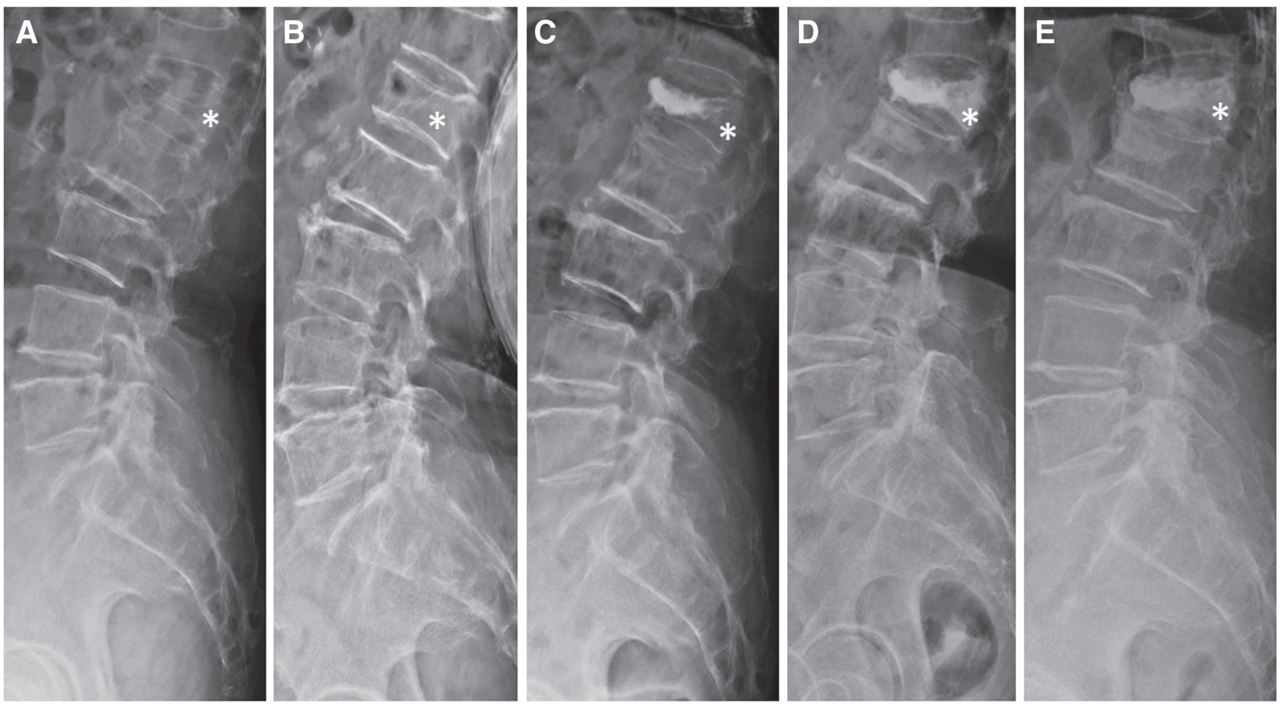

Fig. 3 Illustration of one patient with serial plain radiographs following vertebroplasty (VP). A, Preoperative plain radiograph of the spine (lateral view). B, Lateral fulcrum radiograph (LFR). The measurements of fulcrum flexibility for the vertebral wedge angle (VWA), regional kyphotic angle (RKA), and anterior vertebral body height (AVBH) are 70%, 62%, and 193%, respectively. C, Postoperative plain radiograph of the spine (lateral view). The FRI for the VWA, RKA, and AVBH is 0.86, 0.34, and 1, respectively. D, Postoperative radiograph at 6 months after VP. E, Postoperative radiograph at 28 months. The measurements show that the FRI of VWA, RKA, and AVBH is 0.61, −0.16, and 0.58, respectively. *Compression fracture at the L1 level.

Table 2

Serial changes in VWA, RKA, and AVBH at different follow-up times

	Pre-VP	Pre-VP fulcrum	Post-VP	Post-VP 3 months	Post-VP 6 months	Post-VP 12 months	Latest follow-up
VWA, degrees	16.2 ± 5.41 (7 to 25)	8 ± 5.43 (0 to 22)	10.36 ± 6.44 (–4 to 23)	11.22 ± 6.35 (2 to 27)	10.69 ± 7.58 (–3 to 26)	11.38 ± 6.37 (1 to 26)	12.3 ± 6.95 (1 to 28)
RKA, degrees	22 ± 9.9 (–9 to 38)	9.5 ± 11.4 (–20 to 29)	17.33 ± 10.9 (–8 to 37)	22 ± 11.17 (–8 to 39)	23.8 ± 13.5 (–8 to 45)	24.5 ± 13.14 (–12 to 43)	25.4 ± 14 (–16 to 48)
AVBH, cm	1.31 ± 0.38 (0.63 to 2.16)	1.98 ± 0.41 (1.16 to 2.73)	1.79 ± 0.31 (1.23 to 2.39)	1.65 ± 0.35 (1.13 to 2.44)	1.6 ± 0.33 (1.05 to 2.41)	1.58 ± 0.32 (1.09 to 2.43)	1.55 ± 0.32 (1.03 to 2.42)

AVBH = anterior vertebral body height; RKA = regional kyphotic angle; VP = vertebroplasty; VWA = vertebral wedge angle.

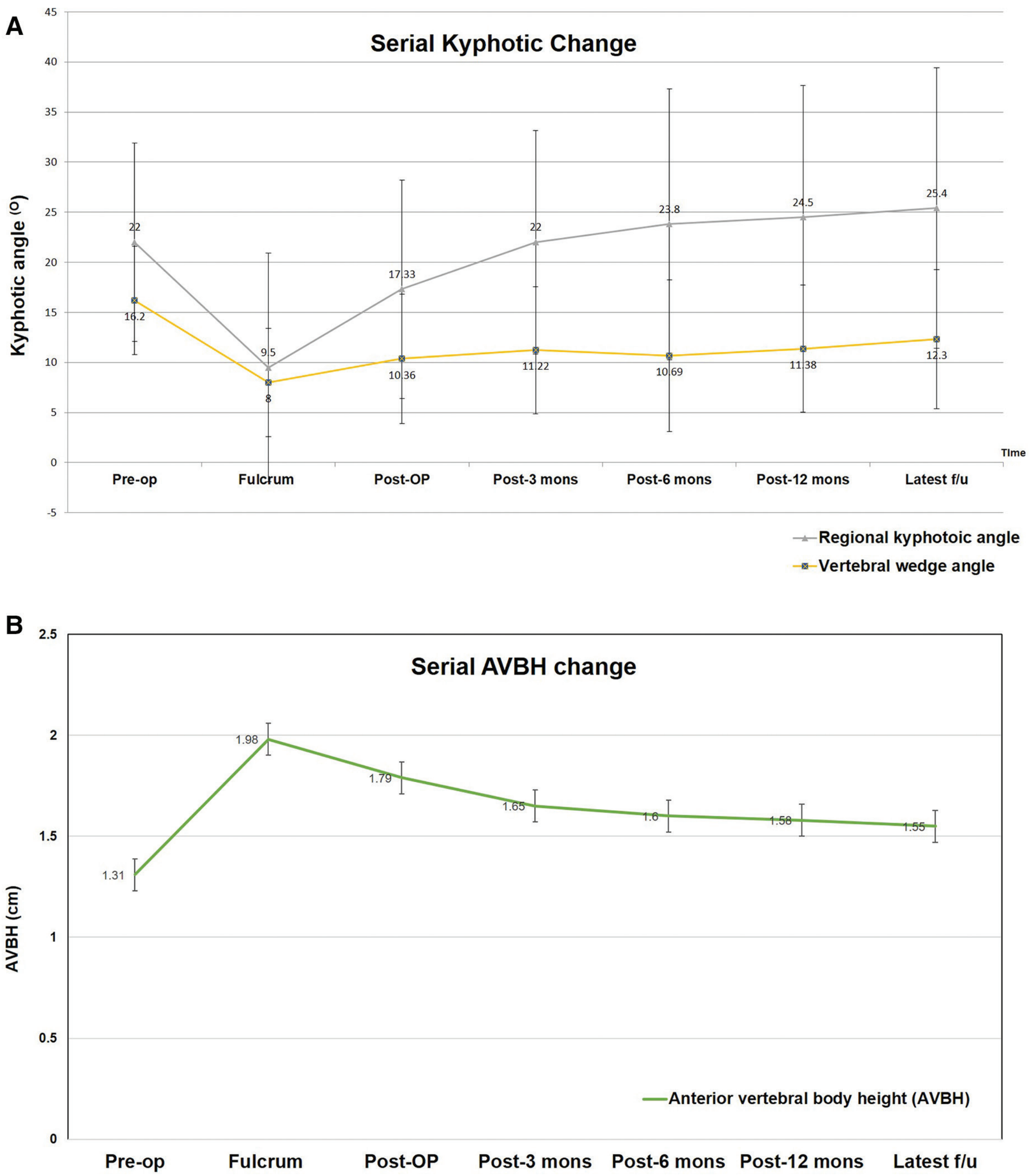

Fig. 4 Serial change in the vertebral wedge angle (VWA), regional kyphotic angle (RKA), and anterior vertebral body height (AVBH) at different follow-up times. A significant progressive loss of restoration is found with time. The error bars indicate SDs. A, VWA and RKA. B, AVBH. mons = months; Post-OP = postoperative; Pre-OP = preoperative.

Table 3

FF and FRI of VWA, RKA, and AVBH at different follow-up times

Radiographic parameters	Pre-VP FF, %	Post-VP FRI	Final FRI	Loss of FRI
VWA	52.4 ± 26 (5 to 100)	1.29 ± 2.98 (−2 to 17)	0.94 ± 2.96 (−3.5 to 17)	0.36 ± 0.97 (−1 to 3.5)
RKA	58 ± 64 (−120 to 260)	0.46 ± 1.16 (−2 to 5)	−0.03 ± 2.25 (−6 to 9)	0.47 ± 2.12 (−7 to 5.3)
AVBH	60 ± 47 (−14 to 165)	1.04 ± 1.68 (−0.7 to 9.5)	0.6 ± 2.04 (−1.05 to 11.8)	0.44 ± 0.72 (−2.3 to 2.1)

AVBH = anterior vertebral body height; FF = fulcrum flexibility; FRI = fulcrum restoration index; RKA = regional kyphotic angle; VP = vertebroplasty; VWA = vertebral wedge angle.

final loss of FRI for VWA, RKA, and AVBH were 0.36 ± 0.97 (range, −1 to 3.5), 0.47 ± 2.12 (range, −7 to 5.3), and 0.44 ± 0.72 (range, −2.3 to 2.1), which indicted similar trends of progressive loss between either two parameters ($p = 0.577$, $p = 0.91$ and $p = 0.691$, respectively).

The FF of AVBH, VWA, and RKA did not correlate with the cement volume, indicating that surgeons cannot use more cement volume to improve restoration ($p = 0.42$ [AVBH vs VWA], $p = 0.91$ [VWA vs RKA], and $p = 0.65$ [AVBH vs RKA], respectively). The preoperative FF was positively correlated with the final loss of FRI in the VWA, RKA, and AVBH parameters. However, there was statistical significance between the preoperative FF and the final loss of FRI in the VWA ($p = 0.03$), which indicated that the fractured vertebrae that had greater preoperative restoration capacity also had the greatest potential loss of FRI in the VWA.

4. DISCUSSION

In our investigation, the post-VP FRI of the RKA did not reach 100%, indicating that VP cannot fully restore the RKA of the fractured vertebrae as predicted by the preoperative LFR. Taking patients' position into consideration, the positions for LFR and VP were measured in the prone and supine positions, respectively. Different positions for either radiologic examination or VP may explain why our FRI did not achieve 100% restoration of the RKA. Intraoperative postural reduction for fracture restoration may be another explanation.[21] Moreover, the definition of RKA included one level above and below the fractured level. These adjacent cephalad and caudal vertebras were normal, but osteoporotic ones without pseudarthrosis may have less potential mobility.

Chen et al.[9] reported a difference of 8.48 mm and 7.5° in AVBH between sitting and use of a 10-cm diameter bolster but did not report the postoperative results. Regarding bolster augmentation, the mobility of the fractured vertebra might be induced and lead to further AVBH and kyphotic angle restoration following VP. In our results, we observed that the average increase in AVBH on the preoperative LFR, post-VP, and final follow-up were 6.7, 4.8, and 2.4 mm, respectively, as compared to the preprocedural AVBH. In our opinion, the larger diameter of the bolster was important in inducing more AVBH and VWA restoration in the fractured vertebra. However, patients may experience more back pain when being examined in the supine position with the augmented bolster in the back, which may bias the bolster-induced restoration effect.

Greater flexibility in the fractured vertebrae correlated positively with greater loss of FRI in the final VWA. The greater flexibility meant that subjects were more mobile at the fractured vertebra, as predicted by preoperative LFR. Togawa et al.[22] reported histologically there was no bony union between the cement and bone, but a thin fibrous membrane was filled. Braunstein et al.[23] confirmed in their investigation that woven bone was found around the injected cement. VP might fill the pseudarthrosis space, but it cannot achieve or induce a solid union between the cement and the osteoporotic bone interfaces. Accordingly, the remaining cortical and cancellous bone of the fractured vertebrae might continue to lose its microarchitecture and lead to age-related kyphosis progression[14,24,25] regardless of whether or not the patient receives VP. This phenomenon may explain why those with FRI of the VWA still progressively lost bone, even after VP.

Our results found cement volume did not correlate with FF in AVBH, VWA, or RKA. In theory, greater flexibility of the fractured vertebral body might lead to more expansion in the LFR; in other words, more cement could theoretically fill the void space or the pseudarthrosis space. Kaufmann et al.[26] reported no significant association between the volume of cement injected and postoperative pain. For safety concerns, surgeons might stop the procedure if the cement leaks to the disc level in cases with a fractured end plate or if the cement reaches to the posterior third of the vertebral body when cement is suspected of leaking into the epidural space.

Pseudarthrosis may be a critical factor for pain relief[27] in VP. To achieve better postoperative outcomes, precise detection of pseudarthrosis, which means identifying the painful vertebrae precisely, is the main prerequisite for surgeons to achieve better clinical outcomes. Based on our results, LFR was equal to MRI scan in its ability to detect pseudarthrosis. An additional clinical use for LFR is to evaluate the potential pseudarthrosis in the fractured vertebra. Based on our results, LFR might have had clinical predictive utility for one-level painful vertebrae only, not for multiple levels of painful vertebras.

Patients' symptoms improved significantly after VP, and quality of life also became better. However, VP is not a good tool for vertebral body restoration compared to posterior instrumentation along with a vertebral body expandable device. Zhong et al.[28] reported VP with bilateral pedicle screw fixation could provide effective restoration of the kyphotic angle as compared to VP only. However, these operations must be performed under general anesthesia, which could increase the incidence of peri- and postoperative comorbidity. Kim et al.[29] found that perioperative complications occurred in 75 of 262 (29%) lumbar fusion surgeries in a geriatric population; 33 of these were major complications. We used local anesthesia for our index VP procedure, which may help avoid such peri- and postoperative comorbidities. The index VP reduced the incidences of postoperative morbidity for the elderly patients and was still effective in relieving back pain and improving quality of life, even though less vertebral body height was restored. Posterior instrumentation and vertebral body augmentation surgery could be reserved for patients who have a poor response to VP.

Pitton et al.[30] reported that VP provided a vertebral height gain of 2.1 mm and increased the end plate angle of 3.20 over 1 year, particularly in cases with severe compression. McKiernan et al.[8] reported that VP restored 8.41 mm of AVBH and 7.18° of vertebral body kyphotic angle in fractured vertebrae. The definition of end plate angle[30] and vertebral body kyphotic angle[8] corresponded to our VWA. In our results, the average postprocedural and final follow-up increases in AVBH were 4.8 and 2.4 mm, respectively. The average postprocedural and final follow-up increases in VWA were 5.90 and 3.90, respectively. Accordingly, progressive loss of RAK, VWA, and AVBH did not compromise the improvement in back pain in our results.

However, the clinical significance of increasing vertebral body height following VP is still unknown.[10]

There are several limitations to this study. First, the enrolled patients were too few to draw definitive conclusions. Second, we did not routinely use computed tomography (CT) scans to evaluate the measured radiographic parameters, which might provide better visualization of bony structures. However, patients might have more radiation exposure with a CT scan examination. Third, intra- and interobserver reliability was not checked, with approximately 5° to 7° in interobserver variability possible during measurements.[31]

In conclusion, we demonstrated that LFR had similar ability to detect pseudarthrosis for one-level painful vertebra of the thoracic and lumbar spine. LFR has clinically predictive utility in evaluating the possible restoration effect of VP to the fractured vertebra. VWA, RKA, and AVBH had similar preoperative restoration capacity. VP had better restorative performance for VWA and AVBH, and VWA had better final maintenance of results. VWA, RKA, and AVBH progressively lost restoration over time to a similar extent independently of VP, but back pain did not correspondingly increase. Surgeons can use this information to better assess patients for surgical planning. Patient expectations of postoperative outcomes in regard to pain and fracture restoration may be also better informed with this knowledge.

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