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ORIGINAL ARTICLE

Comparison of unipedicular and bipedicular kyphoplasty on the stiffness and biomechanical balance of compression fractured vertebrae

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Abstract Percutaneous kyphoplasty (PKP) has been used to treat osteoporotic vertebral compression fractures for over 10 years; however, clinically speaking it is still controversial as to whether the use of unipedicular PKP or bipedicular PKP is best. Our study aimed to compare the different effects of unipedicular PKP and bipedicular PKP on the stiffness of compression fractured vertebral bodies (VBs), as well as to assess how cement distribution affect the bilateral biomechanical balance of the VBs. During this study, 30 thoracic VBs were compressed, creating vertebral compression fracture models; then they were augmented by unipedicular (group A and B) PKP and bipedicular (group C) PKP. In group A (unipedicular PKP), the cement was injected into one side and the augmentation was limited to the same side of the VB. In group B (unipedicular PKP), the cement was injected at only one side but the augmentation extended across the midline and filled both sides of the VB. In group C (bipedicular PKP), the cement was injected into both sides and thus achieved the bilateral augmentation. For the unipedicular PKP, the amount of cement injected was 15% of the original VB volume; while in bipedicular PKP, the amount of cement injected was a total of 20% of the original VB volume (10% was injected into each side). Using a MTS-858, we examined three phases of the VBs (intact, pre-augmented, post-augmented), by applying loads axially to the total vertebra and bilateral sides of the vertebra for each of three cycles, respectively. The changes of force and displacement were then recorded and the stiffness of the total vertebra and bilateral sides of the vertebra were calculated. For the pre-augmentation stage, the total VB stiffness of groups A, B and C significantly decreased when the compression fracture models were established ($P < 0.05$). After the cement augmentation (the post-augmentation stage), both groups A and B, showed that the stiffness could be restored to the initial, intact state; however, in group C, the stiffness was significantly higher than the initial, intact state ($P < 0.01$). The stiffness of the augmented side of group A was significantly higher than the non-augmented side ($P < 0.001$). In groups B and C, no significant differences were observed in the stiffness between total VB and each individual side. Thus, we can conclude that both unipedicular PKP and bipedicular PKP significantly increase the total VB stiffness. Bipedicular PKP creates stiffness uniformly across both sides of the vertebrae, while unipedicular PKP, creates a biomechanical balance depending on the distribution of cement. If bone cement is augmented only on one side, the stiffness of non-augmented side will be significantly lower than the augmented side, which might lead to an imbalance of stress on the VB. However, when cement augmentation crosses the midline, stiffness of both sides increase comparatively and biomechanical balance is thus achieved.

Keywords Kyphoplasty · Stiffness · Biomechanics · Vertebral compression fracture · Cement

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Introduction

Percutaneous kyphoplasty (PKP), which is developed from PVP, has been used to treat osteoporotic vertebral compression fractures (OVCFs) since 1998. Having been used for more than 10 years, PKP has proved its merits—i.e. minimal invasion, quick pain alleviation, safe cement augmentation and the capabilities of the restoration of vertebral height [8, 17]. Currently, the standard procedure for using PKP involves a bipedicular approach; yet, as of date, surgeons cannot reach a consensus on whether unipedicular PKP or bipedicular PKP is optimal for patients.

In March of 2009, *The Lancet* published data from a multi-center, randomized clinical trial of PKP efficiency for OVCFs [23]. This trial demonstrated that, compared with non-surgical treatment, PKP could alleviate patient's pain and significantly improve their quality of life. In the June issue of *New England Journal of Medicine*, other two articles pertaining to two other multi-center, randomized clinical trials showed contrary data indicating that PVP for OVCF held no particular benefit in comparison to a non-surgical treatment [4, 10]. These two printed and published clinical trials aroused a dramatic global controversy because of their negation to the now popular PVP. Questions were raised about why these results were inconsistent with each other. In fact, a discovery of several differences between the former and the latter two studies may have led to these inconsistencies—such as, the criteria of the enrollment sample; type of surgical procedures used (the former was PKP, the latter was PVP); the cement augmentation approaches (the former was bipedicular, the latter two were mainly unipedicular approaches). Upon examining these inconsistencies, it is possible that the approach used with the cement augmentation could actually have an affect on the results. Some clinical studies [19, 24] have uncovered positive evidence that both bipedicular PKP and unipedicular PKP could safely and effectively treat VCFs; some studies on cadavers [20, 21] also showed no significant differences between bipedicular PKP and unipedicular PKP in restoration of the vertebral strength, stiffness, as well as the restoration of vertebral height. Nevertheless, in all of the previously mentioned studies, the parameters measured only tested the total vertebral strength and stiffness; the strength and stiffness of each side of the vertebrae was not determined. From the aspect of biomechanics, biomechanical stabilization of the VBs not only depends on the overall restoration of strength and stiffness, but also on the biomechanical balance of both sides. If a biomechanical balance is not achieved, it may lead to a stress imbalance of VBs and subsequently to a wedging or collapse of the biomechanically weaker side.

Our current study created OVCFs models and performed unipedicular PKP or bipedicular PKP, then measured the stiffness of the total VB, as well as the stiffness on both sides of the VB. We aimed to make a comparison of unipedicular PKP and bipedicular PKP on the stiffness of compression fractured vertebrae, including a comparison in relation to the total VB and both sides of the VB, as well as to evaluate the effect of cement distribution on the biomechanical balance of the VBs.

Material and methods

Cadaveric specimens

30 VBs were harvested from T8 to T12 from 3 male and 3 female fresh cadaveric spines (age 58–75). An X-ray scan was performed to evaluate the spines and make certain that the spines were healthy and without any noted tumors and fractures. A Dual Energy X-ray Absorptiometry (DEXA, GE LUNAR-Prodigy) was used to determine the bone mineral density (BMD) of the vertebrae. The vertebrae were then disarticulated and separated from the spines, then the discs and soft tissues were discarded, and the posterior elements including parts of pedicles were removed. All of the VBs were labeled and wrapped in saline-soaked gauze, sealed in plastic bags, and stored at −20°C.

Compression vertebral fracture models

All of the VBs were thawed at room temperature (20°C) for 1 h before compression. First, bony endplate molds (two molds for created for each VB) of the VB which were made by Polymethylmethacrylate cement (PMMA, Tientsin Synthetic Material Industry Research Institute), were put on or beneath the VB. Then the VB was placed onto a material testing machine (MTS 858 bionix II machine, MTS System Inc., Minneapolis, MN, USA), and a steel plate was put on top of the VB. Compression loads were applied axially to the superior plate along the anterior 1/3 point of the sagittal plane of the VB (Fig. 1, O_0). We set the MTS to give a compression load with displacement at a rate of 5 mm/min. Prior to the initial compression, the anterior VB heights were measured using digital calipers which were accurate to 0.01 mm (Mitutoyo Corporation, Japan).We ceased the compression of the VB when a loss of 25% of the anterior VB height was achieved [6, 20].

Kyphoplasty and groups

The procedure of PKP was completed as previously described [20]. All operations were performed by the

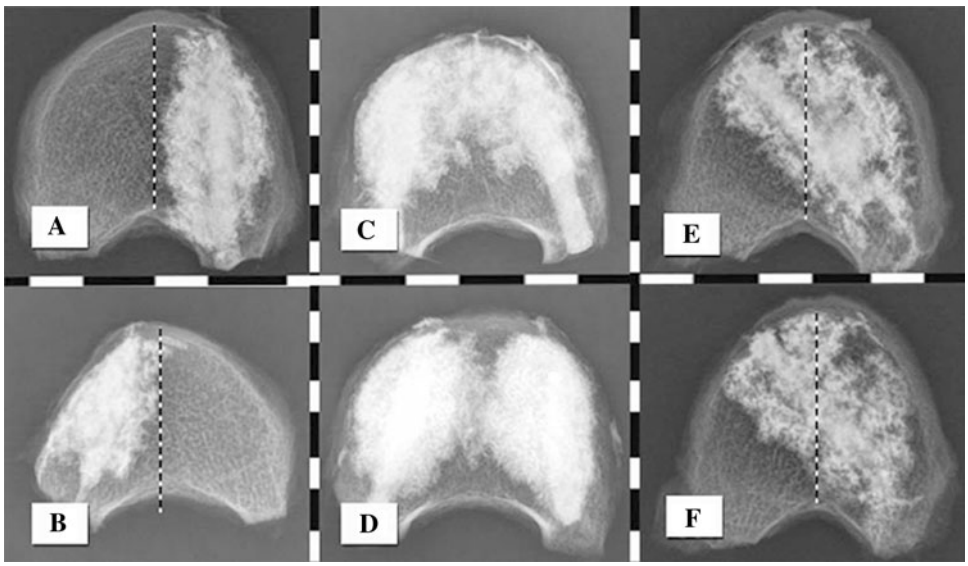

Fig. 1 Axial review radiographs of representative samples of specimens after cement augmentation. Group A: picture **a** and **b**; group B: picture **e** and **f**; group C: picture **c** and **d**

same doctor (C.B.L). In summary, an inflatable bone tamp was inserted into the fractured VB by cannulating either one or both of the VB's pedicles. The balloon was inflated until either the maximum volume of the balloon was reached or until the first signs of an endplate fracture occurred. The resulting cavity was then filled with PMMA cement using the bone filler device (Kyphon).Prior to beginning the PKP, the volume of each VB was precisely measured; the necessary cement volume to be injected into the VB was then calculated according to the volume of each VB (the volume of the VB was measured according to Archimedean displacement). For the unipedicular PKP, the amount of cement injected was 15% of the original VB volume; while in bipedicular PKP, the amount of cement injected was a total of 20% of the original VB volume (10% was injected into each side).

30 VBs were randomly assigned to three different groups: groups A, B, C, respectively, each with $n = 10$. All PKPs were performed under fluoroscopy. In group A (unipedicular PKP), the cement was injected into one side and the augmentation was limited to the same side of the VB. In group B (unipedicular PKP), the cement was injected into only one side and the augmentation extended across the midline and filled both sides of the VB. In group C (bipedicular PKP), the cement was injected into both sides and thus achieved the bilateral augmentation. Following the PKP procedures, all of the VBs were wrapped in saline-soaked gauze, and sealed within a plastic bag at 37°C (to simulate physiological conditions) for at least 24 h to ensure the cement completely polymerized. After 24 h, an X-ray scan was performed on anterior-posterior, lateral, and axial view of each of the VBs (Fig. 1).

Biomechanical testing

The PMMA molds were used to fill the concavity of the superior and inferior endplates of the VB. During the test, the VBs were fixed onto the MTS with two steel plates placed, respectively, onto the superior and inferior endplate of the VB. Compression loads were applied to three different points on the VB (Fig. 2. O_1, O_2, O_3)—O_1 was the midpoint of the mid-transverse line, while O_2 and O_3 were the quarter points on either side of the VB. When the compression loads were applied to O_1, the steel plate on the VB covered the full superior surface in order to measure the total stiffness. When the compression loads were applied to O_2 and O_3, the steel plates on the VB covered one-half of the superior surface, measuring the stiffness of only one side. The biomechanical testing was completed in three phases: Phase 1: initial, VB is completely intact; Phase 2: pre-augmention, VCF model is created; Phase 3: post-augmention. We set the MTS to give continuous compression loads with a range from 0–500 N, in three cycles; the force and displacement data was recorded at 100 Hz. We calculated the stiffness by the mean change of the force and displacement in each of the three cycles. The formula was defined as follows:

$$\text{Stiffness} = \frac{\Delta F_1 + \Delta F_2 + \Delta F_3}{\Delta S_1 + \Delta S_2 + \Delta S_3}$$

Statistical analysis

One-way ANOVA and Bonferroni multiple comparisons were used to compare the VB volume, the anterior height, and the cement volume among the different groups. To compare the change of stiffness among the three phases of the VB, the two-factor ANOVA for repeated measures

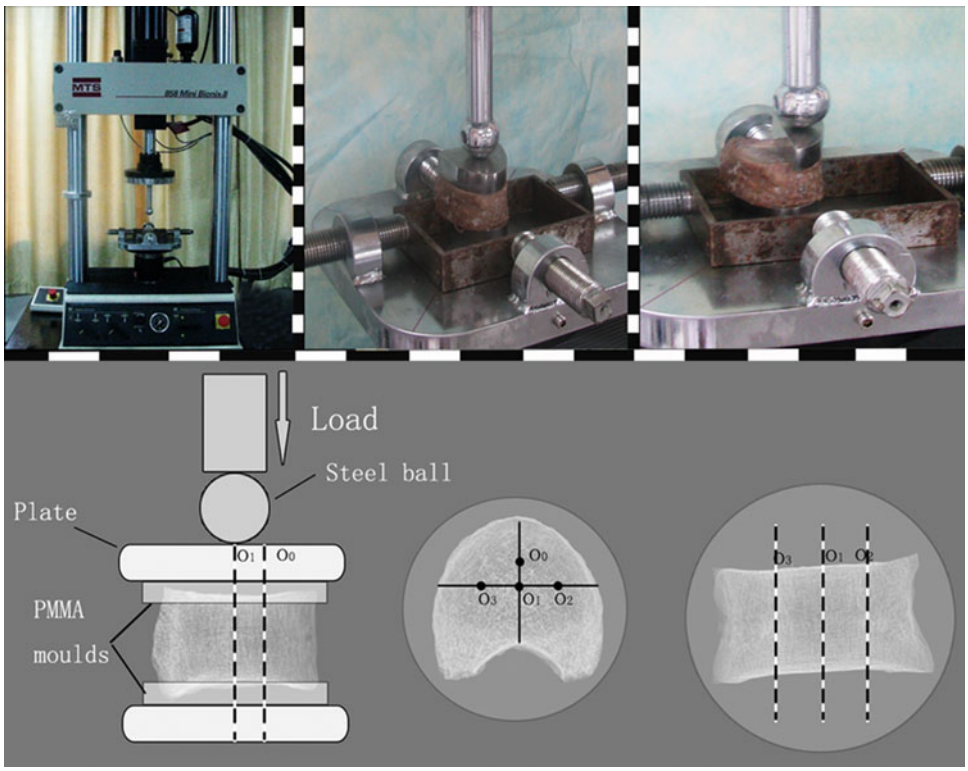

Fig. 2 A display of the mechanical tests used on the specimens. Compression loads were applied to the VB axially. When making the compression vertebral fracture models, compression loads were applied on O_0 (the superior plate along the anterior 1/3 point of the sagittal plane of the VB). When the cyclic compression tests were performed, compression loads were applied to each of the three points, respectively. O_1 was the midpoint of the mid-transverse line, O_2 and O_3 were the quarter points

(Greenhouse-Geisser test) and multiple comparisons were used.

Results

Details of the specimens

The overall information of group A, B, and C is shown in Table 1. There were no statistically significant differences among three groups in the volume of VBs ($F = 0.002$, $P = 0.998$), similar results were found in anterior height ($F = 0.483$, $P = 0.622$) and BMD ($F = 1.376$, $P = 0.27$).

The difference of mean cement volume used in PKP was significant among three groups ($F = 9.717$, $P = 0.001$), Bonferroni multiple comparisons showed that the cement volume of group C was significantly higher than group A ($P = 0.002$) and group B ($P = 0.002$).

The total stiffness of the groups in each of the three phases

The results are displayed in Fig. 3. In phase 1, the VBs were completely intact, and the total stiffness of group A, B, and C were 976.15 ± 160.60, 984.27 ± 84.13 and 986.97 ± 113.67, respectively. There was no significant difference among them ($P > 0.05$).

In Phase 2, vertebral compression fracture models were created. The total stiffness of group A, B, and C were significantly decreased by 43.3, 45.5 and 46.6% (all $P < 0.05$), respectively. However, there still was not a significant difference among the three groups ($P > 0.05$).

In Phase 3, following the PKP procedures, all of the groups demonstrated a significant increase in total stiffness. Group A and B's (the unipedicular PKP procedures) total stiffness was restored to the level of initial, intact state, while group C's (the bipedicular PKP procedure) total stiffness was significantly higher than the initial, intact state (by 22.2%, $P < 0.01$).

The stiffness of each side of Group A, B, and C's VBs

Results are displayed in Figs. 4, 5, 6.

Prior to the PKP procedure. Groups A, B, and C, demonstrated no significant differences between the two sides in phase 1 and phase 2 ($P > 0.05$).

After the PKPprocedure (Phase 3). In group A, the stiffness of the augmented side was restored to initial, intact state; however, the stiffness of the non-augmented side remained unchanged, and thus the stiffness in the non-augmented side was significantly lower than the augmented side ($P < 0.001$). In group B, the stiffness of the punctured side was restored to initial, intact state. Although the stiffness of the non-punctured side increased, the increase was ultimately not very significant when compared to the initial, intact state—the P value was small ($P = 0.07$). Furthermore, there was no significant difference in stiffness

Table 1 Details of group A, B, and C, there were no significant differences in the VB volume, Anterior height and BMD among the groups; the cement volume of group C was significantly more than both group A and B ($P < 0.05$)

Lable	Spine	Level	Group	VB volume (ml)	Anterior height (cm)	BMD (g/cm^2)	Cement volume (ml)
108	1	8	A	23.55	2.21	0.267	3.53
112	1	12	A	33.23	2.56	0.322	4.99
211	2	11	A	25.23	2.62	0.289	3.79
212	2	12	A	27.32	2.73	0.337	4.10
308	3	8	A	19.55	2.15	0.289	2.93
309	3	9	A	19.35	2.16	0.302	2.90
311	3	11	A	22.75	2.37	0.355	3.41
412	4	12	A	35.75	2.62	0.299	5.36
508	5	8	A	20.15	2.11	0.277	3.02
611	6	11	A	25.55	2.51	0.336	3.83
109	1	9	B	25.26	2.30	0.269	3.79
111	1	11	B	27.85	2.42	0.298	4.18
209	2	9	B	22.10	2.15	0.265	3.32
210	2	10	B	23.21	2.27	0.278	3.48
409	4	9	B	30.85	2.35	0.266	4.63
410	4	10	B	31.11	2.45	0.274	4.67
510	5	10	B	20.75	2.23	0.293	3.11
511	5	11	B	22.34	2.35	0.299	3.35
609	6	9	B	24.56	2.45	0.312	3.68
610	6	10	B	24.67	2.48	0.325	3.70
110	1	10	C	26.32	2.32	0.287	5.26
208	2	8	C	21.55	2.12	0.255	4.31
310	3	10	C	21.55	2.12	0.314	4.31
312	3	12	C	24.67	2.41	0.364	4.93
408	4	8	C	24.51	2.33	0.263	4.90
411	4	11	C	33.25	2.51	0.297	6.65
509	5	9	C	20.56	2.05	0.287	4.11
512	5	12	C	27.36	2.44	0.315	5.47
608	6	8	C	23.32	2.42	0.321	4.66
612	6	12	C	28.36	2.57	0.345	5.67
Mean			A	25.24 ± 5.59	2.40 ± 0.23	0.307 ± 0.029	3.79 ± 0.84*
			B	25.27 ± 3.59	2.35 ± 0.11	0.288 ± 0.021	3.79 ± 0.54*
			C	25.15 ± 3.85	2.33 ± 0.18	0.305 ± 0.034	5.03 ± 0.77

determined between the two sides of the VB ($P > 0.05$). In group C, the stiffness of both sides was significantly increased to a state which was actually stiffer than in the initial, intact state ($P < 0.01$); however, there was no significant difference found between the stiffness of the two sides ($P > 0.05$).

Discussion

Reasons for choosing stiffness as the biomechanical parameter

In a majority of the previous studies, both strength and stiffness were the parameters for assessing the biomechanics of the VB. The current study, however, chose only stiffness as the biomechanical parameter for the following reasons: First, there has been strong evidences for a positive correlation between strength and stiffness [9, 12], and stiffness can well predict the strength of the vertebral body [7]; Second, the design of the current study prevented us from measuring strength because cyclic compression tests were needed to determine the biomechanical properties of the total VB and its two sides. If vertebral strength is to be measured, a crush test must be performed, which would damage the VB and severely influence subsequent tests; conversely, measuring the stiffness of the VB is a non-destructive test. For these reasons, like the previous studies [14], the current study chose only stiffness as the biomechanical parameter.

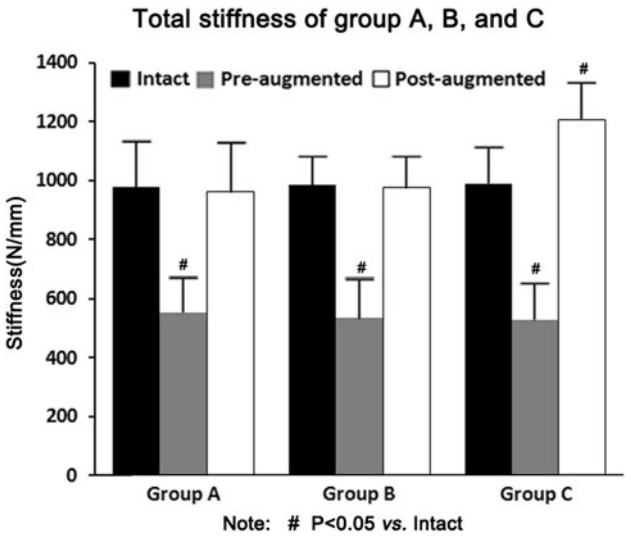

Fig. 3 A comparison of the total stiffness in each phase for groups A, B, and C. A significant increase in stiffness was found in group A, B, and C after the cement augmentation. The stiffness of group C in the post-augmented phase was significantly higher than the initial, intact phase

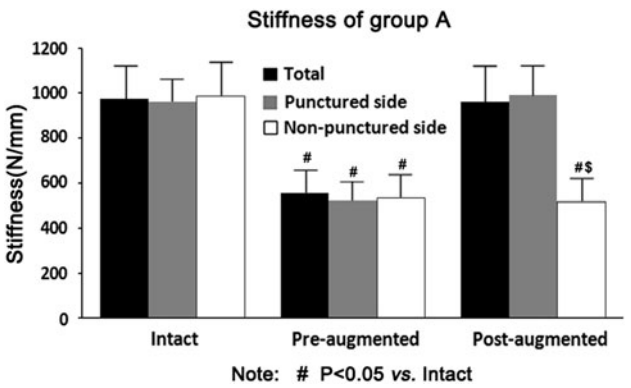

Fig. 4 The stiffness of group A in intact, pre-augmented and post-augmented phases. A display of how the stiffness of the augmented side was significantly higher than in the non-augmented side ($P < 0.05$)

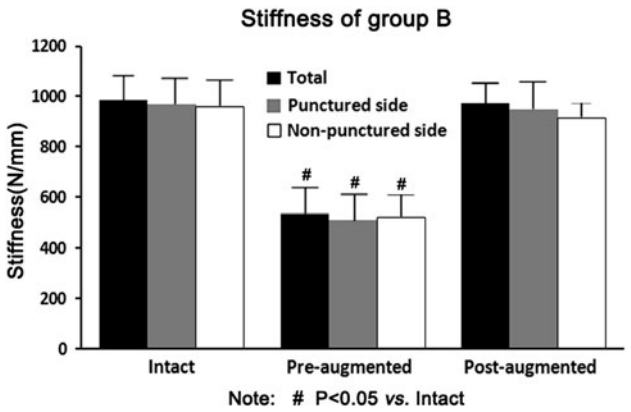

Fig. 5 The stiffness of group B in intact, pre-augmented and post-augmented phases. A display demonstrating that in the post-augmented phase, no significant difference was found between the stiffness of the total VB, the punctured side and the non-punctured side

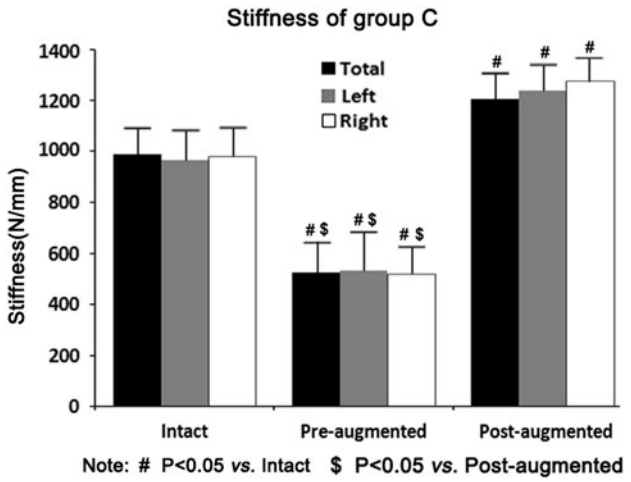

Fig. 6 The stiffness of group C in intact, pre-augmented and post-augmented phases. A display demonstrating that in the post-augmented phase, no significant difference was found among the stiffness of the total VB, the punctured side and the non-punctured side

Unipedicular PKP and bipedicular PKP on the stiffness of a fractured VB

One purpose for conducting this study was to compare the effects of unipedicular PKP and bipedicular PKP on the total stiffness of compression fractured VB. Our results indicated that both unipedicular PKP and bipedicular PKP could significantly increase the total stiffness of a compression fractured VB. However, unipedicular PKP only restored the stiffness to an initial, intact state (or the pre-fractured state), while bipedicular PKP increased the stiffness to a level which was significantly higher than that of the initial, intact state (Fig. 3).

In the past, studies have been performed to compare the effects of unipedicular PKP and bipedicular PKP on the biomechanics of a compression fractured VB. Tohmeh et al. [21] and Steinmann et al. [20] created experimental models of VCF and performed either PVP or PKP to augment the VB. Subsequently crush tests were done, with which the force–displacement curve and the change of VB height were recorded. In Tohmeh's study, both unipedicular PVP and bipedicular PVP were able to restore the VB's stiffness to its initial, intact state, while in the Steinmann experiment, both unipedicular PKP and bipedicular PKP were unable to restore the VB's stiffness to its initial, intact state. However, neither of these two studies showed significant differences between unipedicular and

bipedicular PVP or PKP in the restoration of the VB's strength, stiffness, and height. One factor which may have lead to discrepancies within these two studies results is that the studies used different cement volumes. In the Tohmeh experiment, the cement volume in unipedicular PVP averaged at 6 ml, while the bipedicular PVP was 10 ml. Whereas, in the Steinmann study, the cement volume was much less (mean 2.2 ml in unipedicular and 3.9 ml in bipedicular).

In the current study, both unipedicular PKP and bipedicular PKP significantly increased the stiffness of the fractured VBs; yet, differences still existed in the extent of the increased stiffness. Again, it is possible that the different volumes of cement injected into the VB accounts for the differences in the increased stiffness levels. In the bipedicular PKP trials, the cement volume was 20% of the VB's total volume, whereas, in the unipedicular PKP trials, only 15% of the VB's total volume was used. It has been argued that the injected volume of PMMA has no significant influence on the restoration of VB strength and stiffness [18] and clinical outcomes [1, 11]. Nevertheless, a minimum amount of cement is necessary to effectively restore the stiffness and strength of the VB in order to get acceptable and good clinical outcomes. To date, there has not been a consensus reached on the threshold volume of cement used in either procedure. Molloy's [18] results demonstrated that cement of 16.2% of the VB volume was enough to restore the strength, and 29.8% to restore the stiffness. But Belkoff et al. [2] hold that a volume of only 2 ml of cement was adequate to restore the vertebral strength and 4 ml of cement to restore vertebral stiffness. Furthermore, Liebschner's finite element [15] indicated that a cement volume of less than 15% of the VB could restore the stiffness to pre-fractured level, while an excessive volume of cement might lead to extremely high stiffness and asymmetrical distribution of the cement which would consequently lead to biomechanical imbalance.

Different from the experiments listed above, Luo et al. [16] used thoracolumbar motion segments instead of isolated VBs. After vertebral fractures were induced, the fractured vertebrae received two sequential injections (VP1 and VP2) of 3.5 ml of PMMA cement. Through biomechanical testing, the author concluded that 7 ml cement was required to restore motion segment stiffness (actually, in their study, the stiffness was not restored to the pre-fracture state). However, due to cement leakage, the actual filled volume of cement was 5.43 ml (24.6%) in this experiment, which was only a litter more than in our experiment. In their study, Luo et al. also used a motion segment, which included two vertebrae and an intervertebral disc. The stiffness measured in their study was the total stiffness of the motion segment instead of the cement augmented vertebra. When compression loads were applied to induce a compression fracture, there was potential for both the vertebrae of the segment to have collapsed; yet, only one vertebra of each segment was augmented by cement. More importantly, because the fractured vertebra received two injections of cement at two different points of time, the researchers could not make certain as to whether the cement filled in the first (VP1) and the second (VP2) injection polymerized together or not. Although it is difficult for anyone to conclude for sure, any of these previously mentioned reasons may have had a significant influence on the results of the VB's stiffness.

Boszczyk [3] reviewed the all of the previously discussed literature, including clinical studies [1, 11] and biomechanical experiments [15, 16, 18], and believed that an effective fill would require a minimum of approximately 4 ml PMMA. In our research, the cement volume used in the unipedicular PKP was 3.97 ml (15%), which was similar to the volumes reported being used by Belkoff, Liebschner, and Boszczyk.

Strategically speaking, using less cement to restore the biomechanical strength and stiffness to the initial, intact state of a VB, without exceeding either the strength or stiffness, is optimal for PKP. If the cement distribution and the biomechanical balance of the VB were not taken into account, unipedicular PKP might be more optimal to restore the stiffness and strength of VB, rather than bipedicular PKP.

The cement distribution effects on biomechanical balance in both unipedicular PKP and bipedicular PKP

Proven time and time again, a symmetric cement distribution using unipedicular PKP is not easy to obtain; thus, our study's secondary aim was to assess how cement distribution affected the biomechanical balance of VB in unipedicular PKP and bipedicular PKP. Our results showed that: in unipedicular PKP, when cement augmentation was limited to one side of the VB (Group A), only the augmented side's stiffness significantly increased, without any impact on the non-augmented side. Whereas, when cement augmentation went across the midline and filling the non-punctured side (group B), the stiffness of both the punctured side and the non-punctured side displayed a significant increase in stiffness, actually restoring the VB's stiffness to that of its initial, intact state (this was, to some extent, beyond our original expectations). Regarding the bipedicular PKP (group C), we observed a symmetric increase in stiffness in both sides of the VB after cement augmentation (as we had originally expected) (Figs. 4, 5, 6).

Compared to Tomah's and Steinmann's studies, our study focused solely on how cement distribution effects the biomechanical balance of VBs. Based on our observations, we found that in unipedicular PKP, when cement

augmentation is limited to only the punctured side, the stiffness of the non-augmented side would remain much lower than augmented side, which in turn leads to a biomechanical imbalance in the VB. The finite element study of Liebschner et al. [15] demonstrated this same results. In their experiment, finite models of PVP with different cement volumes and different methods distribution were created. They found that biomechanical imbalance is caused by asymmetric cement distribution in unipedicular PVP, leading to a medial–lateral bending motion toward the untreated (non-augmented) side. Our results indicated the same kind of biomechanical balance, also influenced by the cement distribution in the VB. In terms of biomechanics, such an imbalance of the two sides of VB may predispose the VB to a lateral collapse or wedging of the VB.

However, our findings also showed that, when using unipedicular PKP where the cement augmentation extends across the midline and fills the non-punctured side (group B), a stress balance on both sides of VB could be obtained. With unipedicular PKP being preferred by surgeons because of its shortened operation time and limited risk, our findings are good news. Furthermore, our results revealed the possibility of a biomechanical balance through unipedicular PKP, as long as the cement augmentation is able to cross the midline and fill the non-punctured side adequately. Thus, for facilitating excellent cement augmentation using unipedicular PKP, we should aim to improve our instruments for puncturing the VB [5, 13] and guiding equipment [22].

It is important that we clearly state that in group B (unipedicular PKP with bilateral cement augmentation), we intentionally injected cement across the midline under the guidance of fluoroscopy, so that the cement could adequately fill the non-punctured side. It is still unclear as to the extent and the precise amount of cement filling to the non-punctured side within our experiment; as well as, the extent and precise amount to obtain a perfect and necessary balance of cement augmentation for optimal stiffness within a compress fractured VB.

Conclusion

Both unipedicular PKP and bipedicular PKP have the ability to significantly increase the total stiffness of VBs. Bipedicular PKP has the ability to increase the stiffness of both sides of VB, and creates a necessary biomechanical balance between the two sides. While in unipedicular PKP, the restoration of biomechanical balance depends on the distribution of cement. When bone cement augmented occurs only on one side of the VB, the stiffness of the non-augmented side will be significantly lower than the augmented side, possibly leading to an imbalance of stress on the VB. However, when cement augmentation crosses the midline, increased stiffness is obtained on both sides and there is a strong potential for biomechanical balance to be achieved.

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Conflict of interest None.

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