



Review article

Surgical techniques and clinical evidence of vertebroplasty and kyphoplasty for osteoporotic vertebral fractures

Jae Hyup Lee ^{a, b, c, *}, Ji-Ho Lee ^{a, b}, Yuanzhe Jin ^a^a Department of Orthopedic Surgery, Seoul National University, College of Medicine, Seoul, Korea^b Department of Orthopedic Surgery, Seoul Metropolitan Government - Seoul National University Boramae Medical Center, Seoul, Korea^c Institute of Medical and Biological Engineering, Seoul National University Medical Research Center, Seoul, Korea

ARTICLE INFO

Article history:

Received 18 April 2017

Received in revised form

4 June 2017

Accepted 10 June 2017

Available online 22 June 2017

Keywords:

Augmentation

Osteoporotic vertebral fracture

Kyphoplasty

Technique

Vertebroplasty

Senior osteoporosis

ABSTRACT

Osteoporotic vertebral fracture is a disease condition with high morbidity and mortality, whose prevalence rises with mean increase in the life span. Conventional treatments for an osteoporotic vertebral fracture include bed rest, pain medication and brace implementation, but if the patient's pain is severe, cement augmentation procedures, including vertebroplasty and kyphoplasty, are performed. Vertebroplasty and kyphoplasty are relatively easy procedures that have been reported to be effective in controlling acute pain. But, the risk of complication and additional adjacent segment fracture and their superiority over conventional treatment remain debatable. Therefore, the authors have summarized the procedures, complications, and clinical evidence of vertebroplasty and kyphoplasty in this review.

© 2017 The Korean Society of Osteoporosis. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Although an osteoporotic vertebral fracture (OVF) produces mild symptoms occasionally, most of the times, it causes severe back pain which severely limits patients' behavior and causes public health problems including decreased quality of life and increased medical cost [1,2]. Additionally, it has been reported that an OVF increases mortality [3,4]. Long-term bed rest can increase the risk of various complications, especially in elderly patients; therefore it is critical to use proper pain medication to ensure their mobility. It has been known that commonly used nonsteroidal anti-inflammatory drugs have limited effect on reducing the pain caused by fracture. Other medications for severe pain include opioid-medication, which can cause complications like nausea, vomiting, giddiness, decreased respiratory function, and can increase the risk of falling in elderly patients. Therefore, the medication should be

administered with caution and patients should be followed up positively. Implementation of a brace is another conservative treatment, but old aged patients have lower compliance than young patients, which decreases the effectiveness of the brace. Also, the brace has a disadvantage that it presses the thorax, which limits the user's respiratory function. Therefore, if no significant improvement is observed after several weeks of positive conservative treatment, cement augmentation procedure like injecting polymethylmethacrylate (PMMA) cement into a fractured vertebral body could be an effective treatment [5]. The indication of percutaneous cement augmentation is painful osteoporotic or neoplastic vertebral compression fractures refractory to medical therapy. Cement augmentation has the advantages of ensuring minimal invasion with the percutaneous technique and a relatively short operation time, and therefore, it is used more frequently. Two cement augmentation procedures were widely used, vertebroplasty (VP) and kyphoplasty (KP). In VP, operators insert J-type needles into vertebrae and inject cement, while in KP, the cement was injected after the collapsed vertebrae were expanded with balloons.

To conduct the cement augmentation procedure, the diagnosis of an OVF with a plain radiograph and the diagnosis of a recent fracture with magnetic resonance imaging (MRI) are needed. In case MRI is not available, sagittal reconstruction computed

* Corresponding author. Department of Orthopaedic Surgery, Seoul National University, College of Medicine, Institute of Medical and Biological Engineering, Seoul National University Medical Research Centre, Seoul Metropolitan Government - Seoul National University Boramae Medical Center, 20 Boramae-ro 5-gil, Dongjak-gu, Seoul 07061, Korea.

E-mail address: spinelee@snu.ac.kr (J.H. Lee).

Peer review under responsibility of The Korean Society of Osteoporosis.

tomography and bone scan can be used together to diagnose a recent fracture. Coagulation disorders, infection, and vertebral osteomyelitis are contraindications for VP and KP. In other conditions, like severe posterior displacement of a fractured segment, a lytic lesion in the posterior vertebral wall and a significant defect, the risk of vertebral canal compression is very high, and therefore, they are also contraindications for VP and KP.

Recently, some research has reported that there was no significant difference in the effect of pain reduction between sham injection and VP, which provoked a debate on the usefulness of VP and KP. But according to the meta-analyses reported later, more results showed that VP and KP had an effect of achieving short-term pain control [5–8]. Therefore, this review reports the technical aspects of VP and KP with respect to reduced leakage of PMMA cement, uniportal approach for multiple fractures and KP technique for severe compression fractures.

2. The VP procedure

The basic equipment required for performing VP includes beveled trocars (J-type needle, etc.) PMMA cement, contrast media and a fluoroscope. Patients are positioned in the prone position and they normally receive local anesthesia. A commonly used anesthetic is lidocaine. It is important to position the patients in the true anterior-posterior (AP) and lateral positions since the position of the trocar is critical in these procedures. Additionally, 1 or 2 fluoroscopes should be used to affirm the position of the trocar during the procedure. Nerve tissue might be injured if the trocar invades into the medial side of the pedicle, which should receive increased attention.

A frequently used approach is the transpedicular approach, and the extrapedicular posterolateral approach is used occasionally [9]. Compared to the extrapedicular posterolateral approach, the transpedicular approach has a needle pathway which locates the needle in the vertebral body through a pedicle pathway. The transpedicular approach has advantages of avoiding pleural parenchymal injury, lumbar psoas hematoma and cement leakage by lowering risk of cement leakage through a puncture hole.

2.1. Transpedicular approach

After locating the skin incision 1–1.5 cm lateral to the pedicle lateral margin, a trocar is positioned on the lateral margin of the pedicle using a fluoroscopic AP image. The position should ideally be located at the center or mildly superior to the center of the pedicle. The trocar should be advanced through the pedicle to the posterior margin of the vertebral body, while maintaining the convergence and monitoring with fluoroscopy. The trocar tip should not invade the medial margin of the pedicle on an AP image (Fig. 1). Afterwards, the position of the trocar tip should be checked, and it should be advanced to the anterior 1/5th–1/4th of the vertebral body and the contrast agent should be injected to check for vascular leakage. If vascular leakage is severe, then the position of the trocar tip should be changed and the presence of vascular leakage should be checked again with a contrast agent injection. After that procedure, PMMA cement should be injected slowly (Fig. 1).

2.2. Extrapedicular posterolateral approach

Extrapedicular posterolateral approach can be used in conditions wherein it is difficult to perform the pedicle approach, like patients having a small pedicle, pedicular lysis or instruments like a pedicle screw [10]. Skin incision should be located 4th–5th finger width lateral to the spinous process. When performing this

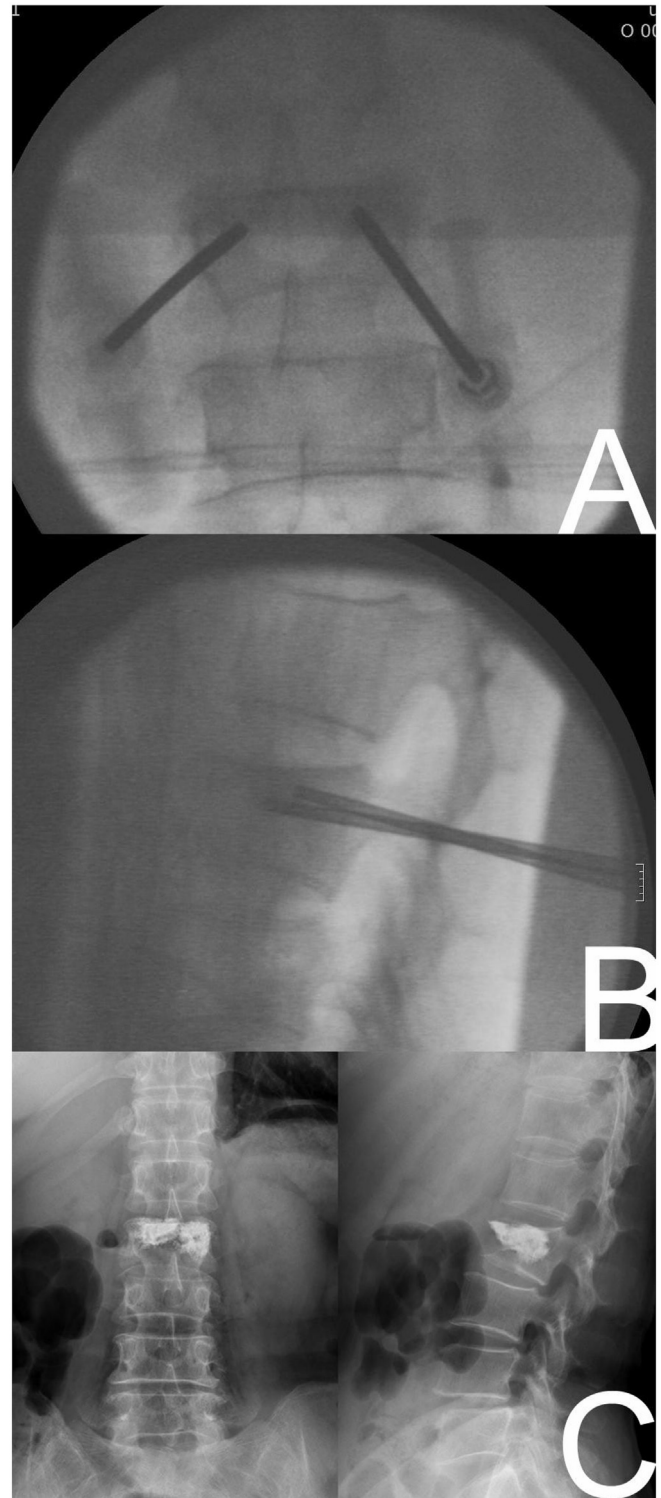


Fig. 1. The vertebroplasty procedure. (A) A J-type needle is positioned at the lateral aspect of the pedicle. (B) A J-type needle is positioned into the vertebral body without invading the medial margin of the pedicle. (C) Image after cement injection.

approach in the thoracic spine, pleural injury and hemothorax should be avoided. The trocar should be located on the anterior 1/5th–1/4th of the vertebral body and cement leakage should be assessed, if it is severe, the position of the trocar tip should be changed, and leakage should be rechecked, as previously described.

2.3. PMMA cement injection

Among the complications of cement augmentation, PMMA bone cement leakage is frequent and it should be looked for because it causes a severe result. The inner diameter of a J-type needle used in VP is smaller than that of a cannula used in KP, and therefore, it is difficult to perform the injection when the viscosity of PMMA cement is high. Extravasations normally occurs during the initial period after cement injection and if the cement leaks into the vein near the vertebral body (Fig. 2), it can enter the lung through the inferior vena cava and cause pulmonary embolism. Therefore, PMMA should be injected while it is not too liquid that it leaks nor too solid. The presence of cement leakage can be checked with injection of contrast media, and if the dye leaks into the vein (Fig. 3A) or the spinal canal, needle position should be changed and the presence of leakage should be rechecked with dye injection. But if the dye continues to leak regardless of the position of the needle (Fig. 3B), it can be helpful to inject the PMMA cement while it has high viscosity. According to the authors' experience, the viscosity of the cement is appropriate if it does not trickle down while it is raised with a spatula. Additionally, successive injection of 0.1 mL of PMMA is safer and the distribution of cement should also be checked with a fluoroscope. If so, even if the dye leaks through a vein, the cement can remain in the vertebral body (Fig. 4).

During vertebral body augmentation, the so-called “needle cast” or “cement tail” could occur, which is due to the solidified cement in the trocar. To avoid the complication, after injecting a proper quantity of the cement with a syringe, the inner cavity of the needle should be blocked with a stylus. If the cement has solidified before the stylus is inserted, the J-type needle should be moved up-down and left-right to break the needle cast and eliminate it with the needle.

2.4. Unipedicular approach

The unipedicular approach can be used in patients with 2 or more vertebral fractures, which occasionally occurs in elderly patients or those who have severe osteoporosis. While performing cement augmentation, factors that need to be considered include risk of excessive use of local anesthesia, pain and fat embolism during the augmentation procedure, decrease in respiratory

function caused by maintaining the prone position during prolonged operation time. Therefore, to reduce the risk of the aforementioned issues, the usage of local anesthesia, the operation time cost and the pain during the procedure should be minimized. A superior method having these characteristics is the uniportal approach. The uniportal approach requires only one side insertion of a J-type needle, which can decrease the usage of local anesthesia to half and groundbreakingly, reduce the pain and the operation time [11].

Compared with performing the bilateral approach, it needs more careful attention as the needle should be positioned in the center of the vertebral body or in the contralateral side of the inserted side to distribute the cement equally during the procedure. Universally, the transpedicular approach with increased convergence or the extrapedicular approach with naturally high convergence can be used to position the needle in the center of the vertebral body. To achieve this purpose, the skin incision should be located 2–3 cm distal to the pedicle for the transpedicular approach or more distal for the extrapedicular approach (Fig. 5).

3. The KP procedure

Compared with VP, KP has advantages of lowering the risk of PMMA cement leakage and can correct the compressed vertebral body. But besides the effect of the balloon, correction of the compressed body is also affected by the position during operation and PMMA cement injection. Therefore, maintaining the extension position is important to restore the previously fractured vertebral body. The minimal period for height restoration of a fractured vertebral body is 4 weeks [12]. The balloon used in KP needs to be positioned in the compressed position, and therefore, the entry point should be positioned with caution, especially in the transpedicular approach. To place the trocar in the optimal position, adjusting the patients to a true AP position and a true lateral position is critical (Fig. 6). After positioning the trocar in the anterior portion of the fractured vertebrae, the guide-wire is inserted into the trocar. Then, a small-sized tube is inserted following the guide-wire and a dilator is used to secure the space for inserting the balloon. Generally, the balloon should reach the anterior part of the vertebral body, and therefore, compared with VP, the tube should be positioned closer to the anterior margin of the vertebral body. A

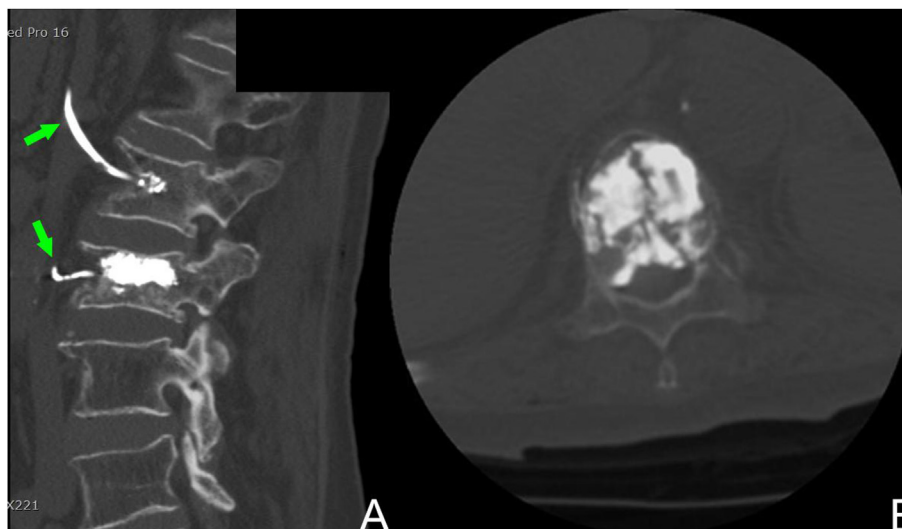


Fig. 2. Polymethylmethacrylate (PMMA) leakage during vertebroplasty. (A) Cement leakage through the vein near the vertebral body. Arrows indicate leaked PMMA cement. (B) Cement leakage through the posterior margin of the vertebral to spinal canal.

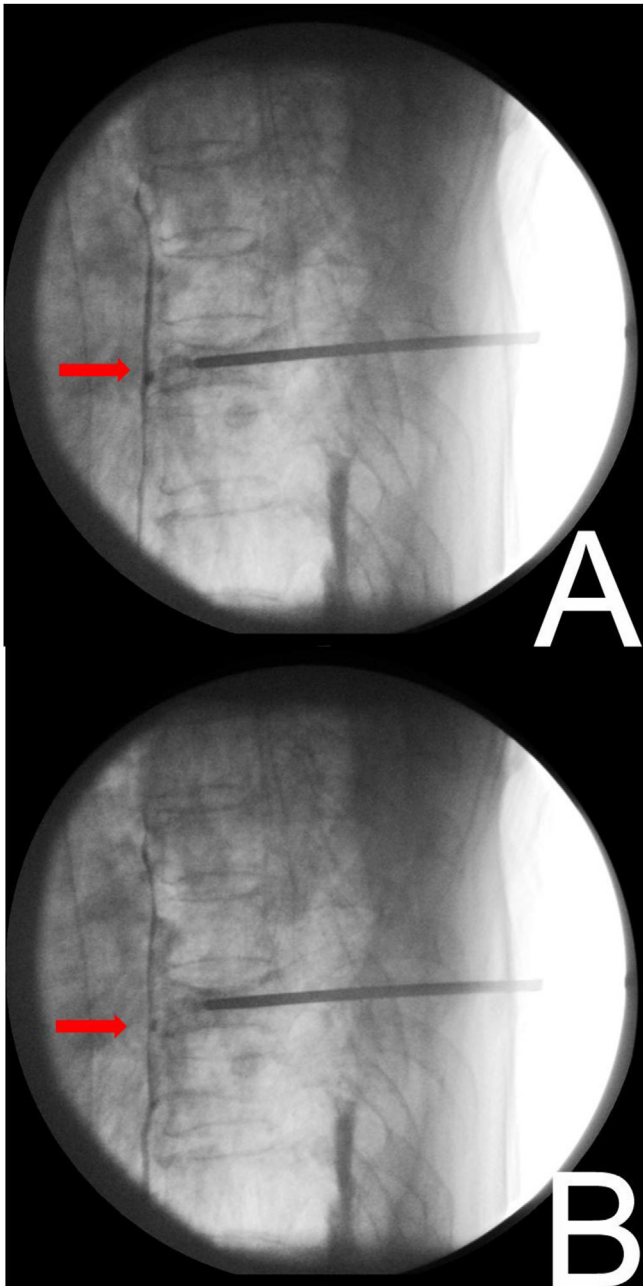


Fig. 3. Leakage is confirmed by injecting the dye after positioning the J-type needle during vertebroplasty. (A) Dye diffuses through the vein near the vertebra (red arrow). (B) Leakage is confirmed by injecting the dye after positioning the J-type needle during vertebroplasty. Dye continues to diffuse through the vein near the vertebra, although the J-type needle is pulled back (red arrow).

fluoroscope should be used to confirm the position of the bilateral balloon (Fig. 6).

The pressure in the balloon should be increased gradually, and the injection of the dye should be stopped when no further correction can be achieved and the pressure increases rapidly compared to the amount of dye injected. Generally, the amount of PMMA cement injected should be similar or slightly less than that of the dye used for inflating the balloon to minimize the risk of cement leakage and to ensure correction of anterior vertebrae. The PMMA cement can be injected at higher viscosity, and similarly, it is safe to slowly inject the PMMA cement with C-arm fluoroscope monitoring in the initial period. It can reduce the risk of cement

leakage, if injection of the PMMA cement is stopped while the pressure increases rapidly. According to the patient's demand, both unipedicular and bipedicular approaches are available for KP. Although no significant difference was reported between the 2 approaches, it was reported that better vertebral height restoration could be achieved via the bipedicular approach [13].

3.1. KP of the severely collapsed vertebra

It is technically difficult to perform KP of an anterior column with a collapse ratio above 70%. Severe collapse of the vertebra can be a result of Kummell disease or severe osteoporosis. The anterior column height in Kummell disease can be restored via the extension position, and therefore, it is easy to position the needle into the vertebra after the patient is placed in the extended position on the operation table. Additionally, other characteristics of cement augmentation treatment for Kummell disease include that VP is enough to restore the anterior column height and use of much more cement than that in the other diseases.

But, additional caution is needed to treat an osteoporotically fractured vertebra which has more than 70% collapse in its anterior column. Unlike VP, in which only positioning the needle into the vertebra is required, in KP, the balloon needs to be totally positioned into the vertebra, and therefore, the position of patients, the insert position and the direction of the needle are critical. Generally, except the convergence, even a 1-mm error is not allowed. Accordingly, it is important to position the fractured vertebra of patients as true AP and true lateral with a C-arm fluoroscope. The needle tip should be positioned at the end of a boost line from the anterior column to the pedicle, and additional caution is needed to avoid invading the endplate of the vertebra during the procedure.

Similarly, it has been reported that even for patients in whom the fractured vertebral body has more than 70% height reduction, KP is effective in reducing the pain and restoring the vertebral height (Fig. 7) [14].

3.2. Postoperative care after cement augmentation

Patients should take approximately 2 hours of bed rest after VP or KP, and they should be allowed to walk when their symptoms become tolerable. Although the operated vertebra is more stable than before, patients still need to wear a rigid brace for 2–3 months because cortical bone healing takes 2–3 months and recollapse might occur during that period. Discharge can be given on the same day or the next day of the operation.

4. Effectiveness

4.1. Pain relief

Although some research reported that cement augmentation has a similar effect as conservative treatment in providing pain relief [15,16] most of the studies reported that cement augmentation has a significantly better effect than conservative treatment with respect to pain reduction [7]. The mean reduction in the visual analogue scale (VAS) pain score after cement augmentation is 4–5 points, and therefore, the threshold of preoperative VAS pain score should be at least 4–5 points.

According to the result of a meta-analysis, the effect of pain reduction caused by VP or KP extended up to the 12th month after the operation [8]. According to the result obtained from another meta-analysis, the pain and dysfunction caused by a OVf were reduced by approximately 90% after VP or KP [6]. But it was reported that KP had a better effect than VP with respect to pain reduction in patients with severe vertebral height loss [2]. In the

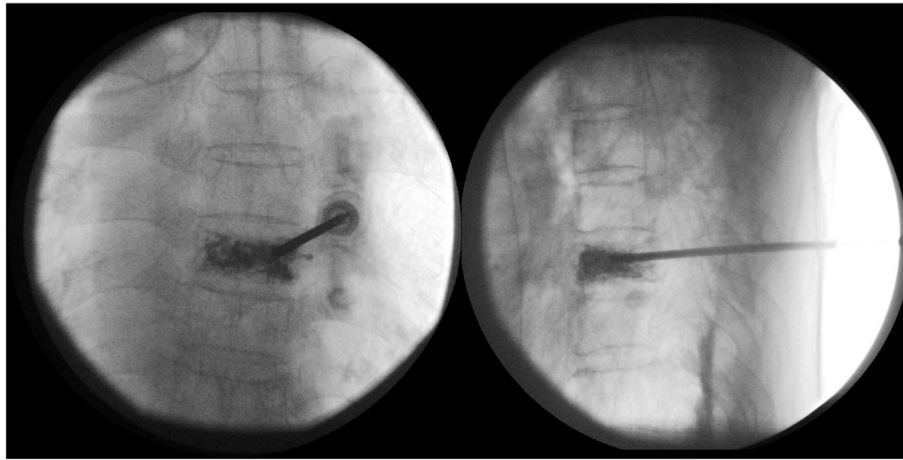


Fig. 4. No leakage occurred in the patient shown in Fig. 3, in whom cement was successively injected at a dose of 0.1 mL and high viscosity. (A) Anterior-posterior image. (B) Lateral image.

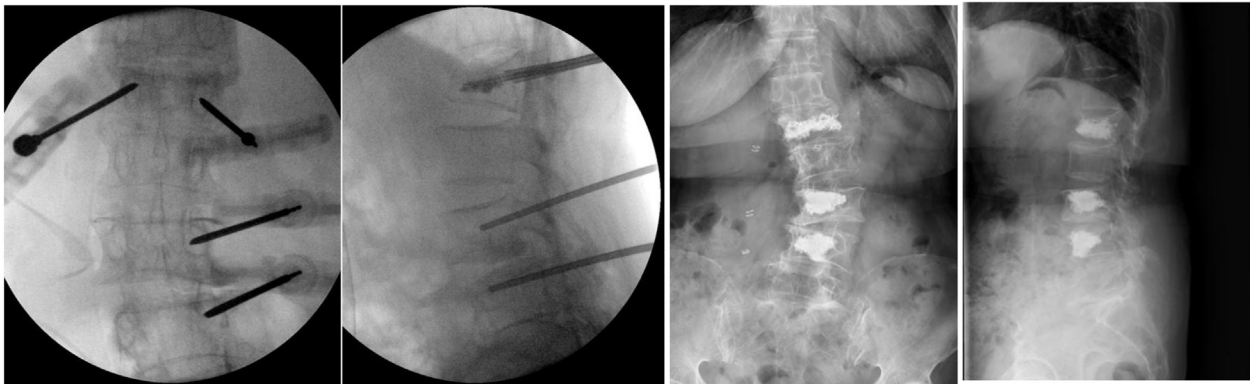


Fig. 5. Use of the combination of uniportal and biportal approaches to treat a 3-level osteoporotic vertebral fracture.

result of a meta-analysis that compared the clinical outcomes between VP and KP, it was reported that KP had a better pain reducing effect both in short-term and long-term VAS scores [6]. The mechanism of the pain reducing effect of cement augmentation might be related to improved micromotion of the fractured vertebra or cytotoxic effect of PMMA cement [17,18].

4.2. Functional improvement

Functional outcome can be measured with the Oswestry Disability Index (ODI), which improved more after KP than after VP. But, in terms of the outcome of 36-Item Short Form Survey (SF-36), VP and KP showed no significant difference [19]. The study reported that VP was associated with a significantly shorter operation time and less amount of PMMA cement injection than KP.

4.3. Radiological results

Theoretically, correction of sagittal alignment of the spine can correct the biomechanical behavior, reduce flexion of the spine and tension of the paraspinal muscles, maintain an upright posture and reduce the pain and risk of subsequent fracture. Especially, the kyphotic angle is a key index that assesses postoperative results of a vertebral fracture. Some research has reported that KP can improve the kyphotic angle by 3.7° – 8° and VP can improve the kyphotic angle by 0.5° – 3° in a vertebral fracture [16]. A meta-analysis also

reported that KP had a better effect than VP with respect to improvement of the anterior and middle vertebral heights in the immediate postoperative period and at the final follow-up [6]. The reason behind why KP has a better kyphotic angle correction effect than VP might be explained by the tamponade effect of the balloon, but the effect of posture in cement augmentation is also important. Although there is a debate regarding the effect of kyphotic angle correction in improving the clinical parameter or the quality of life, some researchers claim that the more is the kyphotic angulation correction achieved, the more is the improvement in the quality of life [20].

4.4. Mortality reduction

Some research has reported that cement augmentation could decrease the mortality caused by an OVF. In a Medicare research, the patients who underwent VP had a 10% survival benefit compared with those who received conservative treatment, the patients who underwent KP had a 23% less relative mortality risk than those who underwent VP [21]. In another Medicare research, the 3-year survival rates in patients who underwent VP and KP were higher than those in patients who received conservative treatment, especially the 3-year survival rate in patients who underwent KP was 20% higher than that in those who underwent VP [7]. But considering the lack of results from a prospective study, the effect of cement augmentation on mortality of patients with an OVF



Fig. 6. The kyphoplasty procedure. (A) A J-type needle is positioned into the vertebral body, same as for vertebroplasty. (B) A small size tube is inserted. (C) The fractured vertebra is reduced with ballooning. (D) Image after kyphoplasty.

needs to be proved by performing additional research.

5. Complications

5.1. Cement leakage

Cement leakage could occur when the PMMA cement is injected at low viscosity or high pressure, and severe complications could develop when an embolism invades the main vessel or viscera. Cement leakage can vary according to the skill of the operator, fluoroscopic equipment used during the operation, the class of cement, cement delivery equipment or the class of cannula. Cardiac tamponade after right ventricular cement embolism caused by KP

has been reported previously [13], and it is known that pulmonary embolism commonly occurs after VP or KP [22,23]. The rates of cement leakage were reported to be 18.1% for KP and 41.1% for VP [24], but the rates of pulmonary embolism were as high as 71% for VP and 41% for KP [25]. The lower rate of cement leakage after KP than after VP could be explained by the void created by the balloon tamponade, which allows injection of cement at lower pressure, and therefore, the cement fills the void preferentially which reduces the rate of cement leakage into the vessels.

5.2. New vertebral fracture

Once PMMA cement augmentation is performed in a vertebral body, the modulus of elasticity of the vertebral body becomes different from that of the adjacent vertebral bodies, which gives them more force. For the reason, some research has reported a higher rate of adjacent vertebral fractures in cement augmentation-treated patients than in the patients treated with conservative treatment. However, more research has reported that there was no significant difference between the ratios of the two treatments [8,23,24], and a research has also reported a lower fracture rate in VP-treated patients [26].

It has been known that the risk factors of adjacent vertebral fracture include cement leakage into the disc space, severity of osteoporosis and the kyphotic angle [2,27]. Additionally, in a meta-analysis which analyzed randomized controlled trials (RCTs) on new vertebral fractures has reported that the relative risk did not increase with implementation of VP (risk ratio, 1.12; 95% confidence interval, 0.75–1.67; $P = 0.59$) [28]. It was also reported that no significant difference was observed in the risk of total new vertebral fracture and adjacent vertebral fracture between KP and VP [6].

5.3. Other complications

Another complication includes penetration of vital organs or tissues while inserting a J-type needle. Penetration-related complications include lung penetration causing pneumothorax, pericardium penetration causing cardiac tamponade and aorta penetration causing major bleeding [7]. Another complication includes infection, which is much more difficult to treat in old aged patients in whom PMMA cement is injected than other spinal infections. Since the treatment of this complication requires surgeries like a corpectomy with high risk of morbidity, mortality after infection can reach 33% according to some research [29].

6. Comparison between unilateral versus bilateral procedures

Bilateral approach with bilateral ballooning is the normal procedure for KP, and theoretically, the unilateral procedure might have an advantage of short operation time but it has disadvantages in kyphotic correction, compared with the bilateral procedure. The research that compares between unilateral and bilateral KP is published continuously. A meta-analysis which included 4 RCTs reported that no significant difference was observed in the short-term and long-term follow-up outcomes, like pain relief, adjacent vertebral fracture, cement leakage, and loss of vertebral height or kyphosis angle reduction, between the 2 procedures. However, the operation time and the injected cement dosage were significantly lower in unilateral KP than in bilateral KP [30].

7. Conclusions

The conditions which indicate that an OVF was treated well include improvement in pain reduction and quality of life, normalization of sagittal alignment like the kyphosis angle and no

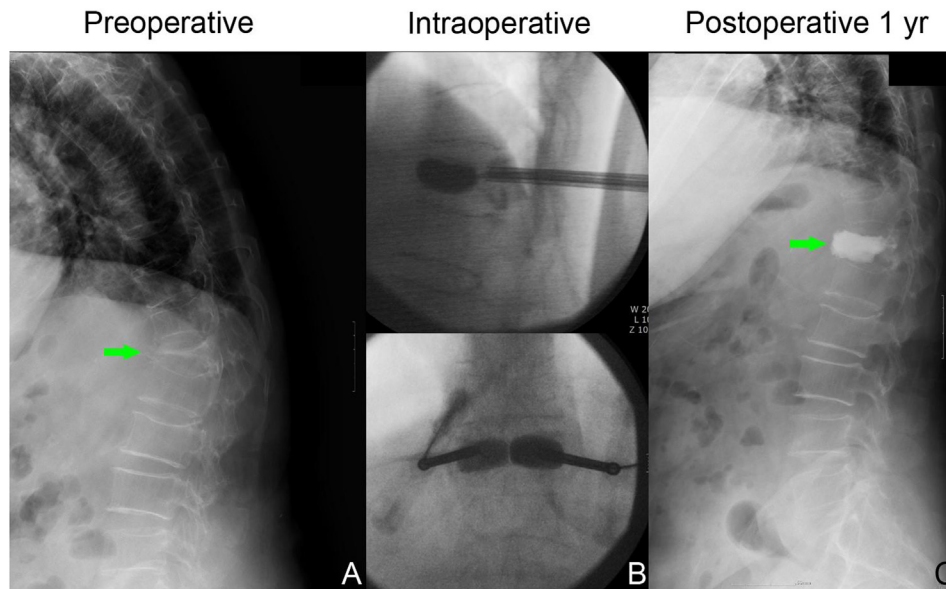


Fig. 7. Successful restoration of height of the severely compressed anterior column with kyphoplasty. (A) The vertebra was severely compressed before operation (green arrow). (B) Plain radiograph during operation. (C) Height of the fractured vertebra was significantly restored by the cement augmentation (green arrow).

additional adjacent vertebral fracture or new vertebral fracture. Performing cement augmentation in patients with an OVf has advantages of easy handling, a relatively low risk of complications and an immediate effect of pain reduction. Besides, it is known that cement augmentation causes functional improvements, like in the ODI and SF-36, and improves the quality of life. Between VP and KP, KP has a better effect in kyphotic angle reduction and a less risk of cement leakage. However, the possibility of cement leakage should be assessed since it is a common complication which can cause pulmonary embolism that threatens the patient's life. The most effective way to avoid cement leakage is to gently inject high viscosity cement and monitor cement leakage with an image amplifier. A uniportal approach multilevel cement augmentation is proper to treat multilevel fractures because it requires less local anesthesia and operation time and reduces the patient's pain [11]. In fracture patients with a severely compressed anterior column, although KP is not a technically easy operation, it is still an effective operation that has a significant effect of pain reduction and kyphotic angle reduction.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

References

- [1] Ma X, Xing D, Ma J, Wang J, Chen Y, Xu W, et al. Risk factors for new vertebral compression fractures after percutaneous vertebroplasty: qualitative evidence synthesized from a systematic review. *Spine (Phila Pa 1976)* 2013;38:E713–22.
- [2] Sanf elix-Genov es J, Hurtado I, Sanf elix-Gimeno G, Reig-Molla B, Peir o S. Impact of osteoporosis and vertebral fractures on quality-of-life: a population-based study in Valencia, Spain (The FRAVO Study). *Health Qual Life Outcomes* 2011;9:20.
- [3] Iqbal MM, Sobhan T. Osteoporosis: a review. *Mo Med* 2002;99:19–24.
- [4] Johnell O. Advances in osteoporosis: better identification of risk factors can reduce morbidity and mortality. *J Intern Med* 1996;239:299–304.
- [5] Guarnieri G, Masala S, Muto M. Update of vertebral cementoplasty in porotic patients. *Interv Neuroradiol* 2015;21:372–80.
- [6] Liang L, Chen X, Jiang W, Li X, Chen J, Wu L, et al. Balloon kyphoplasty or percutaneous vertebroplasty for osteoporotic vertebral compression fracture? An updated systematic review and meta-analysis. *Ann Saudi Med* 2016;36:165–74.
- [7] Papanastassiou ID, Filis A, Gerochristou MA, Vrionis FD. Controversial issues in kyphoplasty and vertebroplasty in osteoporotic vertebral fractures. *Biomed Res Int* 2014;2014:934206.
- [8] Richmond BJ. Vertebral augmentation for osteoporotic compression fractures. *J Clin Densitom* 2016;19:89–96.
- [9] Nussbaum DA, Gailloud P, Murphy K. A review of complications associated with vertebroplasty and kyphoplasty as reported to the Food and Drug Administration medical device related web site. *J Vasc Interv Radiol* 2004;15:1185–92.
- [10] Cho SM, Nam YS, Cho BM, Lee SY, Oh SM, Kim MK. Unilateral extrapedicular vertebroplasty and kyphoplasty in lumbar compression fractures: technique, anatomy and preliminary results. *J Korean Neurosurg Soc* 2011;49:273–7.
- [11] Rebolledo BJ, Gladnick BP, Unnanuntana A, Nguyen JT, Kepler CK, Lane JM. Comparison of unipedicular and bipedicular balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures: a prospective randomised study. *Bone Jt J* 2013;95-B:401–6.
- [12] Guan H, Yang H, Mei X, Liu T, Guo J. Early or delayed operation, which is more optimal for kyphoplasty? A retrospective study on cement leakage during kyphoplasty. *Injury* 2012;43:1698–703.
- [13] Chen C, Chen L, Gu Y, Xu Y, Liu Y, Bai X, et al. Kyphoplasty for chronic painful osteoporotic vertebral compression fractures via unipedicular versus bipedicular approach: a comparative study in early stage. *Injury* 2010;41:356–9.
- [14] Lee JH, Lee DO, Lee JH, Lee HS. Comparison of radiological and clinical results of balloon kyphoplasty according to anterior height loss in the osteoporotic vertebral fracture. *Spine J* 2014;14:2281–9.
- [15] Buchbinder R, Osborne RH, Ebeling PR, Wark JD, Mitchell P, Wrieland C, et al. A randomized trial of vertebroplasty for painful osteoporotic vertebral fractures. *N Engl J Med* 2009;361:557–68.
- [16] Kallmes DF, Comstock BA, Heagerty PJ, Turner JA, Wilson DJ, Diamond TH, et al. A randomized trial of vertebroplasty for osteoporotic spinal fractures. *N Engl J Med* 2009;361:569–79.
- [17] Belkoff SM, Mathis JM, Jasper LE, Deramond H. The biomechanics of vertebroplasty. The effect of cement volume on mechanical behavior. *Spine (Phila Pa 1976)* 2001;26:1537–41.
- [18] Heini PF, W alchli B, Berlemann U. Percutaneous transpedicular vertebroplasty with PMMA: operative technique and early results. A prospective study for the treatment of osteoporotic compression fractures. *Eur Spine J* 2000;9:445–50.
- [19] Wang H, Sribastav SS, Ye F, Yang C, Wang J, Liu H, 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.
- [20] Ranstam J, Turkiewicz A, Boonen S, Van Meirhaeghe J, Bastian L, Wardlaw D. Alternative analyses for handling incomplete follow-up in the intention-to-treat analysis: the randomized controlled trial of balloon kyphoplasty versus non-surgical care for vertebral compression fracture (FREE). *BMC Med Res Methodol* 2012;12:35.
- [21] Edidin AA, Ong KL, Lau E, Kurtz SM. Mortality risk for operated and non-operated vertebral fracture patients in the medicare population. *J Bone Min*

- Res 2011;26:1617–26.
- [22] Abdul-Jalil Y, Bartels J, Alberti O, Becker R. Delayed presentation of pulmonary polymethylmethacrylate emboli after percutaneous vertebroplasty. *Spine (Phila Pa 1976)* 2007;32:E589–93.
- [23] Kollmann D, Hoetzenecker K, Prosch H, Ankersmit HJ, Aigner C, Taghavi S, et al. Removal of a large cement embolus from the right pulmonary artery 4 years after kyphoplasty: consideration of thrombogenicity. *J Thorac Cardiovasc Surg* 2012;143:e22–4.
- [24] Papanastassiou ID, Phillips FM, Van Meirhaeghe J, Berenson JR, Andersson GB, Chung G, et al. Comparing effects of kyphoplasty, vertebroplasty, and non-surgical management in a systematic review of randomized and non-randomized controlled studies. *Eur Spine J* 2012;21:1826–43.
- [25] Denaro L, Longo UG, Denaro V. Vertebroplasty and kyphoplasty: reasons for concern? *Orthop Clin North Am* 2009;40:465–71. viii.
- [26] Alvarez L, Alcaraz M, Pérez-Higueras A, Granizo JJ, de Miguel I, Rossi RE, et al. Percutaneous vertebroplasty: functional improvement in patients with osteoporotic compression fractures. *Spine (Phila Pa 1976)* 2006;31:1113–8.
- [27] Movrin I. Adjacent level fracture after osteoporotic vertebral compression fracture: a nonrandomized prospective study comparing balloon kyphoplasty with conservative therapy. *Wien Klin Wochenschr* 2012;124:304–11.
- [28] Zhang YZ, Kong LD, Cao JM, Ding WY, Shen Y. Incidence of subsequent vertebral body fractures after vertebroplasty. *J Clin Neurosci* 2014;21:1292–7.
- [29] Abdelrahman H, Siam AE, Shawky A, Ezzati A, Boehm H. Infection after vertebroplasty or kyphoplasty. A series of nine cases and review of literature. *Spine J* 2013;13:1809–17.
- [30] Yang LY, Wang XL, Zhou L, Fu Q. A systematic review and meta-analysis of randomized controlled trials of unilateral versus bilateral kyphoplasty for osteoporotic vertebral compression fractures. *Pain Physician* 2013;16:277–90.