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Review Article

Kyphoplasty: A Comprehensive Review of Procedural Techniques, Patient Selection, and Clinical Outcomes in the Treatment of Vertebral Compression Fractures

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Abstract

Kyphoplasty is a minimally invasive surgical technique designed to restore vertebral body height and reduce the associated kyphotic deformity. This intervention is typically performed following unsuccessful conservative therapy. Kyphoplasty must be conducted in the prone position under C-arm fluoroscopic guidance and usually employs local anesthetic techniques by trained practitioners. The procedure involves the percutaneous insertion of an inflatable balloon tamp within the fractured vertebral body in order to restore vertebral height, followed by the injection of polymethyl methacrylate (PMMA) bone cement to stabilize the fracture and increase vertebral stiffness by over 50%. Kyphoplasty is a practical therapeutic option for treating painful vertebral compression fractures (VCFs), considering its typically minor and infrequent complications. This study aims to review the best procedural techniques, as well as appropriate patient selection, to achieve the optimal outcome.

Keywords: Kyphoplasty; Compression Fractures; Osteoporosis; Polymethyl Methacrylate; Minimally Invasive Surgery; Bone Cements

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Background

One common cause of mortality in oncologic patients is spinal fractures. This type of fracture is a result of bone insufficiency as a consequence of osteoporosis, various traumatic events including accidents and sports injuries, malignant conditions (metastatic disease and multiple myeloma), hemangiomas, and osteonecrosis (1, 2). Deterioration of this condition can be accompanied by intractable axial pain and neural compression leading to distortion of neurologic function (2, 3). Kyphoplasty is a new technique often utilized to treat spinal fractures non-responsive to conservative therapy (4-6). Conservative approach for spinal fractures entails bed rest, brace fixation, and analgesics for management of the pain. Despite its deficiencies, such as accelerated bone loss due to prolonged bed rest, gastrointestinal complications due to painkillers, and inability to correct kyphosis, conservative treatment is regarded as the primary approach for managing spinal fractures (7). Kyphoplasty is a minimally invasive percutaneous intervention that involves vertebral augmentation of the fractured spine by injecting polymethyl methacrylate (PMMA) into the vertebral body, reinforcing the spinal column (8).

Methods

A narrative review was conducted by searching PubMed and Google Scholar for literature on kyphoplasty and vertebral compression fractures (VCFs). We included English-language clinical trials, reviews, and anatomical studies focused on procedural techniques, patient selection, and clinical outcomes. Studies with insufficient data or those not primarily focused on vertebral augmentation were excluded. The gathered evidence was synthesized to provide a comprehensive overview of optimal procedural approaches and complication management.

History: The history of kyphoplasty began in 1984, when Galibert and Deramond performed the first percutaneous vertebral cement augmentation at the Department of Radiology, University Hospital of Amiens, France. It was employed by the two surgeons for the treatment of painful vertebral hemangiomas. Their patient was a 54-year-old woman who had severe neck pain. The computed tomography (CT) scan showed a large vertebral hemangioma involving the C2 vertebral body. The operation they conducted was injecting PMMA by a 15-gauge (15G) needle percutaneously into the C2 vertebra by an anterolateral approach (9). Within the next ten-year period, this procedure became prevalent, and enhancements to the technique gave rise to the evolution of kyphoplasty (10).

Multiple studies confirm that percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP) provide rapid and sustained pain relief for osteoporotic VCFs, and are superior to conservative treatments such as rest, bracing, and non-steroidal anti-inflammatory drugs (NSAIDs) (2, 4, 6, 11).

Case: A 70-year-old man presented with persistent back pain following a fall from a 16-foot ladder six weeks earlier (Figure 1). His past medical history was significant for hypertension (HTN), post-traumatic stress disorder (PTSD), and asthma; notably, he presented with no neurological deficits (Figure 1).

Indications and Contraindications: The most important indication of kyphoplasty is relatively new (less than 3 months) painful vertebral fractures, refractory to conservative or medical line of treatment (12).

Figure 1. Computed tomography (CT) scan of first kyphoplasty patient

Other indications comprise painful metastatic lesions with intact posterior cortex of the affected vertebral body (11, 13), chronic painful VCFs with nonunion (14), and progressive kyphosis > 20 degrees in subacute vertebral fractures, which is still controversial (15, 16).

Another indication of cement augmentation is the intravertebral vacuum cleft sign (VCS), also known as vertebral nonunion or pseudoarthrosis (Figure 2). This sign is distinguished by a radiolucent zone in the body of a fractured vertebra in radiographs. This cleft in the vertebral body mainly contains nitrogen (95%) and small amounts of oxygen and carbon dioxide or fluid (17, 18). VCF demonstrates dynamic movement of the fractured bone fragments and a distinctive clinical feature of chronic dorsal pain exacerbated by standing and activity and alleviated with bed rest, known as Kümmell disease (17).

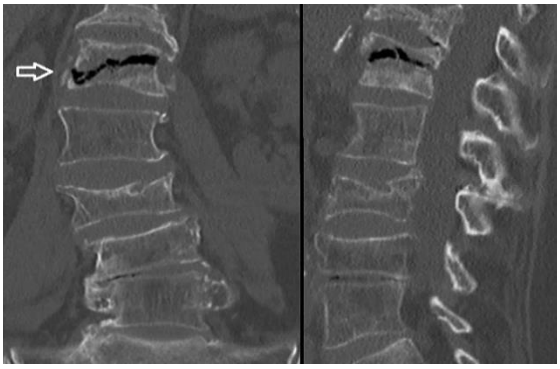

Figure 2. Intravertebral vacuum cleft sign (VCS), coronal and sagittal views of computed tomography (CT) scan

Kyphoplasty has several well-established absolute contraindications, which are conditions where the procedure should not be performed due to a high risk of severe complications or lack of benefit. The most universally-recognized absolute contraindications include active infection, uncorrected coagulopathy, allergy to bone cement, and lack of structural integrity in the vertebral body. Absolute contraindications of kyphoplasty are listed in table 1 (19-22).

Table 1. Absolute contraindications of kyphoplasty

Asymptomatic stable fractures	Symptomatic improvement with medical treatment	Prophylactic vertebroplasty	Symptomatic cord compression
Vertebra plana	Infections: osteomyelitis, discitis	Systemic infections	Coagulopathy
Allergy to bone cements	Complex cortical disruptions where venous, foraminal, or intraspinal PMMA leak appears unavoidable	Myelopathy or neurologic deficit associated with VCF	

PMMA: Polymethyl methacrylate; VCF: Vertebral compression fracture

Preparations before the Procedure

The ideal timing for PVP or PKP is generally after a patient with a painful osteoporotic VCF fails to achieve adequate pain relief or functional improvement with medical therapy. If there is no significant improvement in pain or function after approximately 4 weeks of conservative treatment, medical therapy is considered to have failed, necessitating consideration of alternative interventions such as kyphoplasty (23). This protocol is widely supported among practicing clinicians, as early intervention (following unsuccessful non-operative therapy) can provide rapid pain relief and functional recovery. In contrast, unnecessary early procedures must be avoided for patients likely to recover via non-operative means (4-6).

Operating rooms and radiology departments are the two settings in which PVP and PKP are performed. In challenging clinical scenarios or circumstances necessitating general anesthesia and full surgical support, the operating room is the preferred venue. Alternatively, for scenarios mandating precise needle placement or using conscious sedation, CT-guided vertebroplasty in the radiology department is the preferred option. The latter reduces the procedural duration and radiation exposure with the use of advanced navigation systems (24, 25). Generally, the whole setup required for carrying out these vertebral augmentations must incorporate continuous monitoring of electrocardiography (ECG/EKG), blood pressure, and oxygen saturation (SpO_2). Such systems enable the surgical team to identify adverse events, including cardiac arrhythmias, hemodynamic instability, and hypoxemia during the procedure. All vital parameters require meticulous monitoring, and the facility must be fully prepared for emergency situations, such as cement embolism, hypotension, or cardiac events (26). The surgical setting should be selected by taking into account the surgeon's expertise, the patient's clinical condition, and the accessibility of necessary equipment.

In the context of kyphoplasty procedures, an instrument referred to as the AB needle is typically utilized (Figure 3).

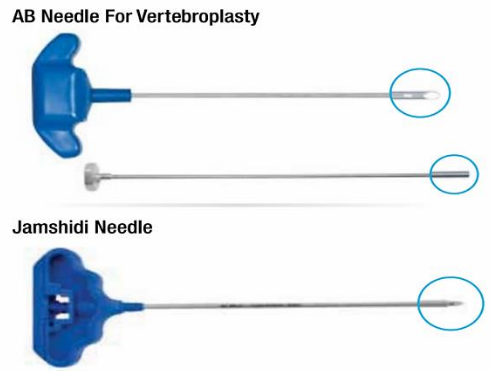

Figure 3. AB needle for percutaneous kyphoplasty (PKP) or percutaneous vertebroplasty (PVP)

This needle is composed of three components: The first part is a long needle with a flanged tip (the angle in the spectrum of 45 to 60 degrees), which is first inserted percutaneously to access the vertebral body and make a pathway for follow-on instruments. The second component is the stylet featuring a sharpened distal tip, which fits inside the needle with a lock arrangement enabling advancement through the bone and facilitating hammering of the needle with its square-shaped proximal head. Following proper anatomical placement of the needle, the stylet is removed, and the pusher is used to advance other devices - such as a balloon for cavity creation or cement delivery through the established channel. Other instruments include a drilling tool, balloon, balloon inflator, and bone cement and its delivery system (8, 27).

The patient should be rolled gently into the prone position under the C-arm image intensifier. C-arm oblique view-assisted PKP can shorten operative duration, improve puncture accuracy, and decrease ionizing radiation exposure while effectively treating osteoporotic VCFs (28). Furthermore, several studies have indicated that advanced navigation systems such as the O-arm can offer even greater precision in complex cases (29, 30). In the prone position, adequate padding is important for a successful procedure. The extremities and the bony prominences, including elbows, hips, knees, and feet, should be well-padded to minimize the risk of pressure ulcers and nerve injuries. Chest rolls are also used to improve ventilation. During longer, multi-level procedures, a Foley catheter can be utilized to manage urinary needs and avoid interruptions during surgery. Intermittent pneumatic compression devices (IPCD) may be used to reduce the risk of deep vein thrombosis (DVT). Sufficient space around the table is necessary for the surgical team and C-arm image intensifier (8, 31, 32).

Continuous, meticulous imaging with the C-arm providing true anteroposterior (AP), lateral, and oblique views is essential during kyphoplasty to verify the accuracy of the needle trajectory, monitor balloon inflation, and, most importantly, detect early signs of cement leakage during injection, thereby preventing serious complications. Studies suggest that advanced imaging techniques - such as combining C-arm fluoroscopy with CT or the application of digital subtraction angiography (DSA) - can further enhance procedural accuracy, shorten the length of the intervention, and lower radiation exposure while simultaneously improving the detection of minor cement leaks (33). Nevertheless, it is essential to have true AP and lateral views (34, 35).

During kyphoplasty in both the AP and lateral imaging planes, several critical anatomical landmarks are essential for safe and accurate needle placement (Figure 4).

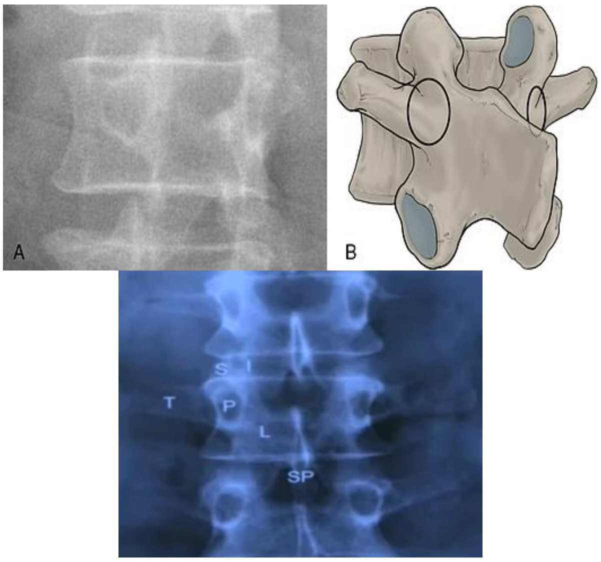

Figure 4. Landmarks during kyphoplasty; (A) Intraoperative fluoroscopic view, and (B) Anatomical illustration of the landmarks, followed by the labeled AP view detailing specific vertebral markers (P, T, L, S, I, SP).

In the AP view, superior and inferior endplates are visualized in addition to the lateral borders of the vertebral body, which helps to define the boundaries of the target vertebra. In the same view, the spinous process serves as a central reference point, and the lateral and medial pedicle margins guide needle trajectory and help avoid neural structures (Figure 5). In the lateral view, anterior and posterior vertebral borders, superior and inferior endplates, and superior and inferior contours and borders of the pedicles serve the same purpose. Additionally, the posterior aspect of the spinal canal precludes the over-injection of cement to minimize the risk of intraspinal leakage (8, 28, 36).

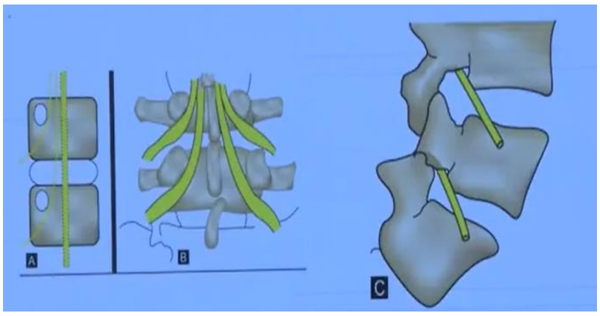

Figure 5. Relation of the pedicle and nerve roots in anteroposterior (AP) and lateral views; A) Schematic representation, (B) Anteroposterior (AP) view, and (C) Lateral view

Before starting kyphoplasty, the spinous process and the sites of the pedicles should be marked on the patient's skin using a marker pen, guided by fluoroscopic imaging. This measure facilitates precise cutaneous entry points and alignment with the vertebral anatomy, reducing the risk of malposition and complications. Furthermore, the operating table is required to be radiolucent for optimal imaging and procedural safety. This enables high-clarity visualization under fluoroscopy in both AP and lateral views throughout the procedure (8, 37).

Surgeons usually prefer to conduct kyphoplasty under local anesthesia, due to its established safety, cost-effectiveness, and a lower incidence of complications compared to general anesthesia, especially in elderly or high-risk patients (38). Local anesthesia is infiltrated from the skin down to the periosteum of the vertebral body, and is often combined with mild sedation for pain reduction during the operation (39, 40). General anesthesia can be used for multi-level procedures; nevertheless, it is associated with an elevated risk of adverse events (39).

For kyphoplasty procedures of the thoracic or lumbar spine, the posterolateral approach is commonly preferred due to its safe and direct access to the vertebral body through the pedicle (8, 41). This approach is categorized into two subtypes: the transpedicular route, which is the most common approach (42), and the parapedicular (or extrapedicular) technique, which serves as an alternative approach for interventions in the superior thoracic spine or in cases where the pedicle is too small and difficult to access (43-45). Both approaches are considered minimally-invasive and safe. Although the transpedicular approach is the most common technique, several studies have made modifications to make it safer and less challenging. Examples include kyphoplasty via the superior pedicle notch or a unilateral transverse process-pedicle trajectory (36, 46). Ultimately, the selection of the optimal approach depends on the vertebral level, the patient's anatomy, and the surgeon's experience.

Procedure of Kyphoplasty

In performing kyphoplasty, initially, under C-arm guidance, a small stab incision is made guided by the relevant anatomical landmarks previously mentioned (8). The typical entry point for accessing the pedicle is at the 10 o'clock position on the left pedicle and the 2 o'clock position on the right pedicle (Figure 6). This trajectory positions the needle parallel to the pedicular axis and helps to avoid surrounding structures (47). Under fluoroscopic guidance, the trocar needle is advanced by hand using light mallet taps to ensure it remains within the pedicle walls. Major resistance is typically felt at two distinct anatomical locations initially upon entering the pedicle, then at the posterior vertebral cortex. This tactile feedback serves to confirm correct passage through the pedicle (8, 41). A key procedural consideration is that the needle should not penetrate the medial or inferior cortex of the pedicle on AP view until it has safely passed through the posterior vertebral cortex and encountered the vertebral body on lateral view (48).

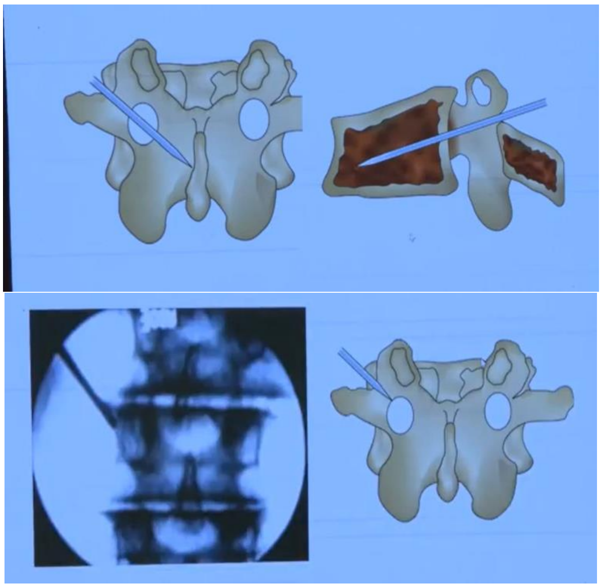

Figure 6. C-arm view, anteroposterior (AP) view of pedicle entry, and AP and lateral views, suggesting final placement of the needle tip

Prior to cement injection, an inflatable balloon is employed in cases where the fractured vertebra is wedge-shaped. The balloon is inserted through the long needle into the vertebral body and then inflated. Through the application of this procedure, the collapsed endplates of the vertebral body are elevated, forming a cavity in the bone, subsequently filled with bone cement. This technique is known as balloon kyphoplasty, which not only restores vertebral body height and corrects kyphotic deformity but also leads to significant pain relief and enhanced functional outcomes for patients undergoing this procedure (7, 49, 50).

The injection of cement must be performed in a slow and cautious manner under C-arm control (Figure 7) (51). If the integrity of the posterior vertebral wall is questionable, injection should be stopped once the cement fill reaches the middle third of the vertebral body (52). High injection pressures must be avoided to prevent sudden extravasation (53). Ideally, cement should fill up the anterior body of the vertebra, crossing the midline to the other side, and then to the posterior part of the body (54). Cement leakage can occasionally occur, especially through the lateral cortex or superior endplates, most often in patients with fractures involving the superior endplate. These leaks are of no major clinical consequence. However, large-volume leaks - particularly into the venous system or spinal canal - can cause serious complications, including pulmonary embolism or the development of neurological impairments (22, 55).

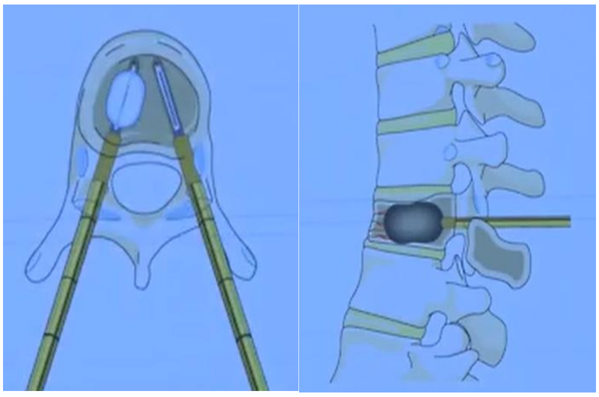

Figure 7. Cementing of the vertebral body

The application of bone cement results in increased stiffness of the vertebral body, often by more than 50 percent (56). Typically, about 3 cc of cement or approximately 30% of the vertebral body volume is considered adequate for most cases. However, the precise volume must be determined based on individual vertebral body size and characteristics of the fracture. Studies indicate that greater volumes of cement fill do not necessarily provide improved biomechanical results; in fact, an excessive volume of cement can lead to over-stiffening, which may elevate the risk of fractures in adjacent vertebral levels and disrupt the natural biomechanical balance of the spinal column (57).

Lastly, the five most important commandments are as follows: Practitioners must be trained to recognize the appropriate point of cessation for injections and to manage cement leaks, as immediate intervention can prevent serious complications. High-quality equipment is essential to monitor both needle trajectory and cement injection. The cement must be opacified, and continuous fluoroscopy is needed during every step. Moreover, ensuring proper indication for the patient is a primary requirement (8, 58-60).

Conclusion

Kyphoplasty is an established, safe, and effective intervention for patients with symptomatic VCFs, providing rapid pain relief, improved function through a degree of stiffness restoration, and partial recovery of vertebral height. Careful patient selection with careful observance of indications and contraindications, skilled technique for needle placement, and appropriate cement volume management are essential in order to avoid complications, such as cement leakage or adjacent vertebral fractures, and optimize the advantages of kyphoplasty in clinical practice. Although conservative therapy remains the first-line approach, kyphoplasty has a lower complication rate and may reduce mortality risk compared to conservative management.

Conflict of Interest

The authors declare no conflict of interest in this study.

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