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Review Article

Minimally Invasive Fixation in Osteoporotic Vertebral Fractures: A Review Article

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Abstract

There are several surgical strategies which have been proposed to treat the osteoporotic patient with vertebral fracture, ranging from vertebral body cement augmentation, percutaneous/mini-open short segment pedicle screw fixation, and cortical bone trajectory screw to kyphotic deformity correction surgery. Minimally invasive spine surgery has the potential benefits of faster recovery, reduced blood loss, less postoperative wound pain, lower infection risk, and shorter length of hospital stay. Novel surgical techniques such as percutaneous instrumentation fixation, cortical bone trajectory technique, screw cement augmentation, and vertebral body augmentation are developed. However, various complications have been reported, including pedicle fracture, instrumentation loosening, adjacent-level disc degeneration with herniation, and progressive junctional kyphosis. The purpose of this review was to outline various advancements in minimally invasive spinal surgery for patients with osteoporosis. Minimally invasive surgical techniques for fixation including percutaneous instrumentation, cortical bone trajectory technique, screw cement augmentation, and vertebral body augmentation have benefited patient with osteoporosis. Studies and discussions about short-segment pedicle screw fixation (one level above and below the fracture level) have shown that it provides enough stability for thoracolumbar burst fractures. There are also complications, including cement embolism, adjacent vertebral fracture, neuraxial anesthesia, and infection, which have been observed with the above technique. With the advancement of instrument and technique, the complication rate decreased in recent studies. Minimally invasive fixation still has many advantages for patients with osteoporosis. Many of these studies and strategies only have evidence from biomechanical and cadaveric studies and require further clinical trials to establish their clinical efficacy.

Keywords: Osteoporosis; Spinal Fracture; Review; Minimally Invasive Surgery; Bone Cement

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Background

Osteoporosis, the most prevalent bone disorder in the world, weakens and thins bones, causing breakage of the bony microarchitecture. The decreased bone density leads to bone fragility and diminished structural support. Factors leading to osteoporosis include age, gender, diet, lifestyle, medications, and autoimmune diseases that disrupt the balance between osteogenesis and bone resorption. Approximately, 18% to 26% of postmenopausal women worldwide experience osteoporotic vertebral fractures (1-3). Studies have shown that 41% to 59% of patients undergoing spinal surgery have osteopenia, and 10% to 51% have osteoporosis (4).

Several surgical strategies have been proposed to treat the osteoporotic spine, ranging from vertebral body cement augmentation, percutaneous/mini-open short segment pedicle screw fixation, and cortical bone trajectory screw to kyphotic deformity correction surgery (5). However, various complications have been reported, including pedicle fracture, instrumentation loosening, adjacent-level disc degeneration with herniation, and progressive junctional kyphosis (6, 7). The reported incidence of adjacent junctional kyphosis ranged from 20% to 40%, especially when the instrumentation end sat at a kyphotic segment or at the transitional area (8, 9).

Minimally invasive spine surgery has the potential benefits of faster recovery, reduced blood loss, less postoperative wound pain, lower infection risk, and shorter length of hospital stay (10-12). With the guidance of intraoperative fluoroscopy, percutaneous pedicle cannulation across long levels could be achieved with a smaller incision and less paraspinal muscle destruction. The purpose of this review was to outline various advancements in minimally invasive spinal surgery for patients with osteoporosis. According to the Scale for Assessment of Narrative Review Articles (SANRA) (13), we used the MeSH terms "spine/surgery" AND "osteoporosis" AND “minimally invasive” to find all the relevant articles from 01-01-1990 to 04-20-2022 in PubMed, MEDLINE, Embase, and the Cochrane Library. A total of 1083 articles were found, of which 272 full-text articles were available. We accumulated all of the articles that described minimally invasive techniques to improve the fixation strength of implants in osteoporotic spine fixation.

Minimally Invasive Surgical Techniques for Fixation

Percutaneous Instrumentation: The common consensus is that pedicle screws with larger diameters, longer lengths, and smaller cortical bone insertion holes have better torque, which can improve the strength of pedicle screws (14). In addition to conventional pedicle screws, percutaneous pedicle screws are increasingly

common. The standard procedure of percutaneous pedicle screw placement is using a Jamshidi needle to cannulate the pedicle under fluoroscopy or three-dimensional (3-D) navigation and then placing the Kirschner wire (K-wire) through the Jamshidi needle. After that, the instrument, such as the tapper, and the cannulated screw along the wire must be changed. It is possible to advance the K-wire to break the anterior wall of the vertebrae and to injure the great vessel, especially in the osteoporotic spine. With a designed pedicle finder (Figure 1), we can simplify this procedure under only the anterior-posterior (AP) view of fluoroscopy and avoid changing the instrument along the K-wire (Figure 2) (15). However, the cortex of the pedicle is thinner in osteoporotic spines, which decreases the strength of the screw (16).

Figure 1. The assembled owl enables approximately 2 mm of the sharp tip of the Kirschner wire (K-wire) to be exposed. The anterior portion (40 mm long) ensures proper path creation for pedicle screw insertion. B: The first part is a metallic handle, a 120-mm long cannulated trocar with a diameter of 8 mm, and another 40-mm anterior portion with a diameter of 3 mm. The anterior portion includes a 10-mm long shallow screw thread that provides low purchasing power while screwing the instrument to cannulate the pedicle. The second part is a cap with a shortened K-wire.

According to the patient condition and involved levels, the surgical strategy has to be adjusted.

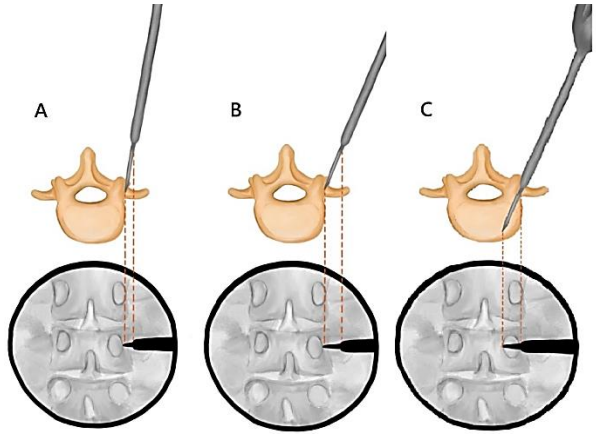

Figure 2. Under the anterior-posterior (AP) view of fluoroscopy, the anterior slender 40-mm portion was used to estimate the angle of pedicle screw insertion. After determining the entry point and the instrument direction (A), the instrument was slowly screwed into the target pedicle (B). The shallow screw thread at the instrument tip made the purchase power too weak to break the cortex bone, and this kept the instrument inside the pedicle while the instrument was advanced by screwing (C).

Mini-Open Short Segment Fixation: A burst fracture requires stabilization in patients with osteoporosis, especially at the thoracolumbar junction (17). Long segment pedicle screw fixation (more than one level above and below the fracture level) is a superior and rigid way to treat these patients. However, long segment fixation is associated with many biomechanical and physiological changes, including sacrificed spine motion and adjacent segment disease (9, 18, 19). Therefore, long segment fixation had high perioperative morbidities in elderly fragile patients (9).

Short-segment pedicle screw fixation (one level above and below the fracture level) has been shown to provide enough stability for thoracolumbar burst fractures in several studies (20, 21). However, the failure rate was initially as high as 50% and decreased to 4%-8% in recent studies with cement augmentation and improvements in screw design (22-24). Wu et al. showed that four-segment fixation was the better choice for osteoporotic bones in their analysis (19).

Cortical Bone Trajectory Technique: Osteoporosis affects cancellous bone more than cortical bone. A pathway with more cortical contact was developed. Cortical bone trajectory is a fusion technique for screw insertion that was first described by Santoni et al. in 2009 (25).

The entry point is at the junction of the center of the superior articular process and 1 mm inferior to the inferior border of the transverse process (Figure 3) (26). The trajectory was directed cranially toward the posterior one-third of the superior end plate and directed straight forward in the transverse plane. Cadaveric biomechanical analyses in lumbar spines of uniaxial pullout strength demonstrated that screws of cortical bone trajectory had 30% higher pullout strength than traditional pedicle screws (27). The entry point and trajectory are different from the traditional pedicle screw pathway, which can reduce incision length, resulting in less muscle dissection and blood loss. It also decreases the injury to the facet joint compared to the traditional pedicle screw pathway. This can benefit patients by reducing postoperative back pain. Huang et al. demonstrated a percutaneous technique with a previously mentioned designed cannulated awl for cortical bone trajectory in lumbar spine surgery (28). It can reduce radiation exposure to the surgeon and minimize incision and paraspinal muscle injury.

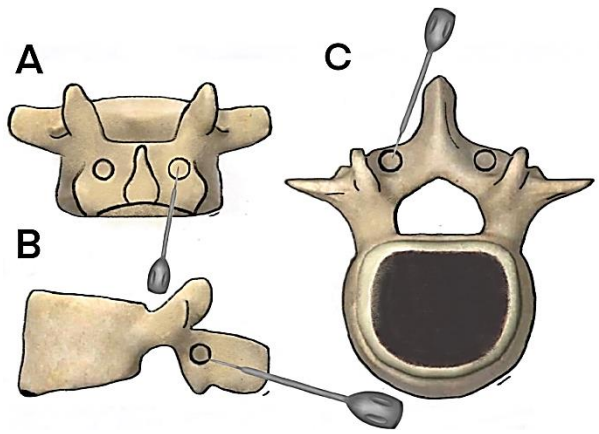

Figure 3. A: Typical entry point of cortical bone trajectory with the owl under anterior-posterior (AP) view; B: Typical entry point of cortical bone trajectory with the owl under lateral view; C: The entry point and pathway of the cortical bone trajectory under axial view

Screw Cement Augmentation: Moore et al. (29) and Wuisman et al. (30) reported that calcium phosphate and

calcium apatite cement augmented screws could increase the pullout strength by 102% and achieve maximum strength at 24 hours. Chevalier et al. also reported that cement augmented screws increased pullout strength by up to 48% to 94% and bending stiffness by up to 1.5% to 6.9% (31). In addition, hydroxyapatite (HA) augmentation improved the interface between the screw and bone, which reduced the risk of angular displacement of the screw and prevented screw subsidence. Cement augmentation decreases the revision rate by approximately 13.7% (32). Some studies also used polymethyl methacrylate (PMMA) augmentation. Frankel et al. reported that PMMA augmentation increased the pullout strength by 119% to 162% (33). Wang et al. also reported increased pullout strength by 52.8% to 72.7% of PMMA augmented screws in patients with osteoporosis (34). However, PMMA has many disadvantages, including its exothermic properties and risk of neural injury when extravasated. Thus, most spine surgeons use biodegradable cements as the first choice. However, cement leakage is a major concern and may become a fatal problem. Potential locations of leakages include the disc, foraminal, paravertebral space, local venous system, and central vascular system with migration to the cardiac or pulmonary system (35). A mortality case with pulmonary infarction with severe acute respiratory distress syndrome after cement leakage was also reported (36). The cement leakage rate was 2.1% to 26%, and the incidence rate of PMMA leakage was 2.33% (35, 37).

Vertebral Body Augmentation: The vertebral augmentation technique includes various techniques, such as simple injection of cement (vertebroplasty), reduction balloons (balloon kyphoplasty), implant insertion (SpineJack ® system), and radiofrequency kyphoplasty (RFK). These techniques can treat osteoporotic spines at several levels simultaneously by a percutaneous approach with a small incision.

Percutaneous vertebroplasty was first introduced by Galibert and Deramond in 1984 for treating hemangiomas (38). Spine surgeons developed vertebroplasty for compression fractures with failed conservative treatment to relieve back pain and correct deformity. Two randomized controlled studies published in the New England Journal of Medicine showed that vertebroplasty had no greater benefit in alleviating pain from osteoporotic vertebral compression fractures (39, 40). These two studies were also criticized by many papers with perceived flaws, including lack of blinding and excluding patients with acute fractures in the research methods and results (41). Further studies support that vertebroplasty relieves pain and improves functional outcomes (42, 43).

Various complications, including cement embolism, adjacent vertebral fracture, neuraxial anesthesia, and infection have been observed. The rate of cement leakage is high and ranges from 54% to 75% (44, 45). Most leakages are asymptomatic, but serious complications of nerve root or spinal cord compression and pulmonary embolism must always be considered.

Percutaneous balloon kyphoplasty (PKP) is an improved technique based on vertebroplasty for reducing the cement leakage rate and improving vertebral height restoration (46). Compared to vertebroplasty, the rate of bone cement leakage can be reduced to 1%-8% (47). Studies have shown that vertebroplasty has a small effect on vertebral body height recovery, and balloon kyphoplasty allows temporary height restoration with new vertebral fracture (48, 49).

Meta-analysis showed that both vertebroplasty and balloon kyphoplasty were cost-effective compared to conservative treatment for osteoporotic vertebral fractures (50).

The SpineJack® system, which is a titanium implant with PMMA or cement injection, has been designed to restore the height of the vertebral body. It facilitates the support of the collapsed vertebrae by mechanically stabilizing the vertebral body in axial compression (51). The SpineJack® system could also treat traumatic fractures in young and middle-aged patients by using the combination of implants and cement (52). Noriega et al. showed that the SpineJack® procedure was an effective, low-risk procedure for patients with traumatic vertebral compression fractures (53). Compared with balloon kyphoplasty, SpineJack® was proven to reduce mechanically compressed vertebral bodies and maintain height restoration (53-55). However, all these benefit and good outcome studies were short-term follow-up studies. Further long-term clinical and radiological outcomes are still needed.

RFK was introduced in Germany in 2009 with a unipedicular approach (56). The procedure inserted an articulating osteotome into the vertebral body through the pedicle, and several small channels were created within the cancellous bone of the fractured body with ultra-high viscosity cement injection, which preserves more intact cancellous bone than balloon kyphoplasty. Studies have shown that it can improve back pain and pulmonary function [forced expiratory volume in 1 second (FEV1)] and lower mortality (57). Compared with balloon kyphoplasty, RFK has a shorter operational time with less damage to the trabecular bone, fewer postoperative fractures and secondary loss of height restoration (57).

Conclusion

Minimally invasive fixation has many advantages for patients with osteoporosis. However, many of these studies and strategies only have evidence from biomechanical and cadaveric studies and require further clinical trials to establish their clinical efficacy. With all the recent advances in instruments and implants, surgeons should be open to novel thoughts and techniques.

Conflict of Interest

The authors declare no conflict of interest in this study.

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