Screw Fixation in Patients with Osteoporotic Spine

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Osteoporosis is a common disease in elderly populations and is a major public health problem worldwide. It is not uncommon for spine surgeons to perform spinal instrumented fusion surgeries for osteoporotic patients. In patients with severe osteoporosis, instrumented fusion may result in screw loosening, implant failure or nonunion because of a poor bone quality and decreased pedicle screw stability as well as increased graft subsidence risk.

pedicle screw percutaneous pedicle screw osteoporosis spine

1. Basic Principle of Pedicle Screw Fixation for Osteoporotic Spine

Appropriately sized and positioned pedicle screws are important for obtaining optimal fixation in the osteoporotic spine [1]. Larger diameter screws have been shown to improve the pullout strength of pedicle screws [2][3]. However, oversizing the pedicle should be avoided because some larger screws may result in pedicle fracture of the osteoporotic vertebrae [2][4]. It has also been reported that the length of the screw improves pullout strength [3]. In addition, undertapping the pedicle screw tract increases pullout strength [1][5][6]. The same diameter tapping of screws decreases the insertional torque and consequently reduces the pullout strength of the pedicle screw. Therefore, it has been recommended that the surgeon should undertap the path of the pedicle screw in patients with an osteoporotic spine [6].

2. S2AI Screws

There is increasing evidence that pelvic fixation may become the standard method of various instrumented spine surgeries [7]. Pelvic fixation is an important method of ensuring stability at the base of long construct fusions and should be considered in patients with a long construct ending in the sacrum, those with associated risk factors for loss of distal fixation or a high risk of pseudarthrosis at L5–S1 and those undergoing three-column osteotomies or vertebral body resection in the lower lumbar spine [7][8]. In addition, pelvic fixation can also be indicated for patients with high-grade spondylolisthesis, unstable sacral fractures, sacral tumors and insufficiency fractures [7][8]. In corrective surgery for osteoporotic patients with severe spinal deformity in particular, pelvic fixation is a very useful method of obtaining rigid fixation [9].

Long constructs extending from the thoracic spine to the distal lumbar spine and/or sacrum result in large lever arms and cantilever forces, causing substantial stress at the base of the construct. Furthermore, pedicle screws placed at S1 have a significant risk of screw loosening, especially in elderly patients with osteoporosis, as the S1 pedicles in the sacrum largely include cancellous bone [8][10]. Therefore, pelvic fixation is very important for ensuring a stable construct base and maintaining surgical correction of the spinal deformity until bony fusion is achieved [8].

3. Intra-Sacral Buttress Screws

While pelvic fixation using S2AI screws provides strong stability at the base of the construct [11], the impact of S2AI screws on the sacroiliac joint remains uncertain in the long term. Recently, Fukuda et al., reported a novel fixation method using intra-sacral buttress screws (ISBSs) that is strongly stabilized by the sacral subchondral bone without penetration of the sacroiliac joint [12]. In this fixation method, a screw with a polyaxial head is inserted into the lateral sacral mass and assembled to the rod connected cephalad to the pedicle screws. The dorsal side of the screw can then be stabilized by the sacral subchondral bone at the sacroiliac joint with iliac buttress coverage, while the tip of the screw is anchored by the sacral cortex [12].

4. Cortical Bone Trajectory Screws

The cortical bone trajectory (CBT) screw technique is another pedicle screw insertion method described in 2009 by Santoni et al. [13]. The CBT screw fixation within the pedicle is targeted in a mediolateral path in the axial plane and a caudocranial path in the sagittal plane [13]. This screw trajectory engages the cortical bone and theoretically provides increased cortical bone contact, increased screw grip and a reduced reliance on trabecular bone [14]. CBT screws were reported to have a higher insertion torque than traditional pedicle screws in vivo [15]. Several biomechanical analyses have shown that the CBT screw/rod construct has favorable mechanical properties [16][17].

5. Penetrating Endplate Screws

Previously it has suggested that modified pedicle screw insertion techniques penetrating the superior endplate of the vertebral body can be useful for enhancing the screw fixation strength [18][19][20][21]. Recently, Matsukawa et al., reported the penetrating S-1 endplate screwing technique [18]. The penetrating S-1 endplate technique, through the medial entry point, is suitable for the connection of lumbar CBT screws. This trajectory engages with denser bone maximally by the screw penetrating the S-1 superior endplate through a more medial entry point than the traditional technique [18]. This screwing technique has favorable stability for lumbosacral fixation and reduces the potential risk of screw loosening and implant failure [18]. It also has several safety advantages, with the protrusion of the screw tip into the intervertebral disc space carrying no risk of causing neurovascular injury [18]. A biomechanical study demonstrated that the new technique demonstrated greater insertional torque than the traditional monocortical technique [18].

6. Groove Entry Technique and Hooking Screw Technique

Previously it has suggested that the groove entry technique and hooking screw technique for thoracic percutaneous pedicle screw (PPS) fixation may provide greater screw stability than conventional pedicle screw fixation [22][23]. In these techniques, the PPS enters at a dorsal site craniolateral to the pedicle, where the cortical bone is thicker than at the caudal aspect of the pedicle, and passes obliquely through the thickened cortical bone [22]. These screwing techniques utilize the strength of posterior vertebral elements with purchase on the transverse and articular process and endplates, transfixing the pedicle in a diagonal fashion, and hugging the strong cortex of the neuroforamen and spinal canal [22]. The diagonal trajectory allows for longer screw insertion, and longer screws have more contact with bone and are better able to engage the anterior column than shorter ones [23]. Therefore, diagonal screw instrumentation, such as the groove entry technique and the hooking screw technique, may provide sufficient anchoring strength to prevent implant failure [22][23].

7. HA Stick and HA Granules

It has been reported that the placement of substances into the tapped screw hole increases the bone–metal interface friction force and enhances the mechanical strength of screw fixation [24][25][26][27][28]. Osteoconductive ceramic bone graft materials, such as HA and calcium phosphate, have received attention as clinically available biomaterials to increase the stability of screw fixation [25][29].

Several previous ones have suggested that an HA stick or HA granules inserted into the tapped screw hole may help enhance the initial strength of pedicle screw fixation [24][30][31]. For more than two decades, the augmentation technique of pedicle screws using an HA stick has been widely used in spinal surgeries in various countries [24][32]. Previous ones have indicated the biomechanical advantage and clinical usefulness of this augmentation technique [24][30][32].

8. PMMA

PMMA bone cements appear promising for the augmentation of pedicle screw fixation biomechanically in both osteoporosis and revision spine surgery models [33]. Burval et al., reported that pedicle screw augmentation with PMMA improves the initial fixation strength and fatigue strength of instrumentation in osteoporotic vertebrae [34]. Becker et al., demonstrated that the augmentation of fenestrated pedicle screws with PMMA provided higher pullout resistance than nonaugmented screws [35]. Chen et al. [36] demonstrated that prefilling PMMA with solid screws resulted in improved axial pullout strength compared with injecting PMMA through a fenestrated screw. A recent study reported a clinical usefulness of percutaneous pedicle screw fixation with cement augmentation in surgical treatment of thoracolumbar fractures in patients with ankylosing spondylitis [37].

However, there is a risk of cement extravasation leading to potentially neurological or cardiovascular complications with cement use [32][33]. In addition, cements, including PMMA, have exothermic properties that may induce bone necrosis and the degeneration of adjacent discs [33][38]. PMMA has no potential for inducing bone remodeling, osteoinduction, osteoconduction or osteointegration and may block the vascular supply by its presence.

Furthermore, cement augmentation may increase the risk of fracture of the vertebra during screw removal [39]. Therefore, both risks and benefits of the cement augmentation should be considered in order to achieve successful outcomes in spinal fusion surgery for osteoporotic patients.

9. Expandable Pedicle Screws

Several biomechanical studies demonstrated that expandable pedicle screws improved screw pullout stability compared with standard pedicle screws in osteoporotic spines [40][41]. It has also been reported that expandable pedicle screws can decrease the risk of screw loosening and achieve better fixation strength and clinical results in osteoporotic lumbar spine fusion [42].

However, expandable pedicle screws carry a risk of vertebral bone destruction during screw removal, which may cause nerve root or dural injury [42]. Nevertheless, an application of expandable pedicle screws might be considered in addition to the standard pedicle screws and the cement-augmented screws in surgical treatment for an osteoporotic spine.

10. Sublaminar Band

Previous ones have suggested that a sublaminar band can be useful for augmenting screw fixation [43][44]. A biomechanical study using a human thoracolumbar spine revealed that pedicle screws augmented by a sublaminar band provided firmer fixation of screws and a stiffer pedicle screw/rod construct than the same construct without augmentation [44]. Another study showed that a sublaminar band and titanium clamp were useful for reducing and maintaining correction of the thoracic curve in surgical treatment for adolescent idiopathic scoliosis [45].

The polyester sublaminar band is soft and flexible, and the anterior–posterior spinal canal space occupied by the band is less than that taken by a sublaminar wire steel cable, thus avoiding direct spinal cord trauma during sublaminar passage. The flat configuration of the cable distributes the load over a larger contact area under the lamina than metal wires without producing imaging artefacts on postoperative magnetic resonance imaging (MRI) [46]. In contrast to sublaminar wiring, the use of the polyester belt may help reduce the risk of long-term complications associated with bone destruction [43]. Therefore, the sublaminar band may be considered as an alternative augmentation technique for screw fixation in osteoporotic spines [43].

11. Hook

Previous biomechanical ones was demonstrated that the augmentation of the pedicle screw with a laminar hook can improve stability of the spinal instrumentation [47][48][49]. The combination of pedicle screws and laminar hooks can achieve greater instrumentation stiffness than pedicle screws alone [47][49]. In addition, supplemental offset hooks significantly increase construct stiffness without sacrificing principles of short-segment pedicle instrumentation, and absorb some part of the construct strain, thereby reducing pedicle screw bending moments.

Therefore, augmentation with a hook may reduce the risk of postoperative implant failure associated with pedicle screw fixation [48].

Several have reported that a central hook–rod construct is effective for spinal osteotomy site closure [50][51]. In addition, the central hook–rod construct may strengthen the overall pedicle screws and rod construct and consequently avoid postoperative screw loosening and implant failure [50][51].

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