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Review

Surgical treatment of spondylolisthesis using long arm screw: A literature review

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ABSTRACT

Background: Spondylolisthesis refers to anterior displacement of the vertebral body in reference to the bordering vertebral bodies, causing segmental instability, that mostly occurs in the middle lumbar spine and the lumbosacral junction. If surgery is indicated, open technique with lumbar pedicle strew instrumentation is the standard therapy. Recently, minimally-invasive technique can be applied in spondylolisthesis surgery using percutaneous long-arm pedicle screws with a promising short- and long-term outcome.
Objective: This paper reviews the development of minimally-invasive percutaneous long arm pedicle screws from techniques to reported outcomes.
Conclusion: Minimally-invasive surgery utilizing advance techniques and instrumentations can give a better outcome in spondylolisthesis surgery associated with lesser blood loss, pain level, and length of hospitalization.

1. Introduction

Spondylolisthesis refers to anterior displacement of the vertebral body in reference to the bordering vertebral bodies, causing segmental instability. There are 6 broad categories depending on its etiologic cause, including isthmic, traumatic, degenerative, pathologic, dysplastic, and postsurgical. The most common occurrence is the degenerative spondylolisthesis, which affect elderly patients with mean age ranging from 71.5 years to 75.7 years with higher prevalence in female. Degenerative spondylolisthesis most commonly affects the lower lumbar spine, although cervical and thoracic spine involvement have been reported secondary to trauma [1]. It is one of the most common cause of low back pain in United States, affecting around 11.5% population [2].

Controversy exists regarding the optimal management strategy for patients with spondylolisthesis [3]. Patients with symptomatic pain may be first treated with conservative management such as non-narcotic and narcotic medications, steroid injections, and physical therapy. If there's failure in conservative management, surgery is appropriate [2]. The standard treatment is open pedicle fixation and spinal fusion to address the instability, or open decompression and in situ fusion to decompression purpose only. However, open techniques have been associated with extensive blood loss and soft tissue dissection, which further lead to more post-operative pain, lengthy hospitalization and higher cost. Minimally-invasive percutaneous spondylolisthesis reduction technique offers solutions to overcome those tissue dissection-related outcomes.

2. Pathophysiology

The spine has natural curvatures in the sagittal plane with cervical and lumbar lordosis and thoracic and sacral kyphosis. These curvatures are normally balanced, thus allowing the muscles of gait and posture to work efficiently [4]. Under normal condition, anterior spinal column supports most of the axial load while the posterior column support 10–20% of the load. The load on a lumbar disc is a combination of an axial force and shear force because the nature of its oblique orientation of lumbar vertebral endplates. The posterior aspect lumbar spine act as a tension band resisting the force of one vertebral body on another preventing anterolisthesis. Annulus fibrosis of the intervertebral disc and the posterior longitudinal ligament also provide some resistance against spondylolisthesis.

The exact cause of spondylolisthesis is not entirely understood, however the combination of familial and acquired factors are a likely to establish a certain specific anatomic and mechanical environment that

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cause a slip to happen [4]. Biomechanical factors play an important role in the development and progression of spondylolisthesis. Degenerative type spondylolisthesis is thought to be a result of osteoarthritis of facet joints and instability of ligament [5].

Once spondylolisthesis is developed, it can cause pain associated with nerve compression and instability. Furthermore, the slippage will disrupt the sagittal balance and cause further morbidities.

3. Diagnosis

History taking and physical examination are the first diagnostic approach in order to determine the treatment and management of spondylolisthesis [6]. Interspinous gap changes during the flexion and extension of the lumbar, is performed in order to detect any signs of lumbar instability, of which both are performed while standing upright. First, patients are requested to flex their back, and the physician observes from the uppermost point until the base (cranial-caudal). The physician then proceeds to apply some pressure on the patients' hip toward the table located in front of the physician, resulting in lumbar extension from the previously flexed state. Tenderness is evident when the interspinous spaces are palpated with a wider gap, appearing during the shift from flexing to extending [7]. However, it has been speculated that tightness or spasm in the paraspinal muscles secondary to pain when standing may have a splinting effect, thus reducing the apparent instability on flexion-extension radiographs. Pain leads to decreased intervertebral motion in symptomatic patients with spondylolisthesis.

The role of imaging or radiology examination is to support the clinical diagnosis of degenerative spondylolisthesis. Modalities that can be used are X-ray, MRI single and triple sequence, CT Scan, USG dan myelographic [8]. Upright lateral and oblique plain radiographs can provide some information regarding the grade and the type of spondylolisthesis. Spondylolisthesis may completely reduce during supine MRI or CT imaging, but the slip became evident on weight bearing radiograph. MRI is useful in degenerative spondylolisthesis because it can show specific degenerative changes in facet joint such as facet hypertrophy or laxity surrounding the ligaments. Spinal stenosis could also be shown by using MRI [5].

Meyerding developed a grading system by measuring the number of shifts as the percentage of the vertebral diameter below the shifted vertebra. Meyerding defined the grade I with a range of shift between 0 and 25%, grade II between 26 and 50%, grade III between 51 and 75%, grade IV between 76 and 100%, and grade V (spondyloptosis) more than 100% (Fig. 1) [8].

The second method, first described by Taillard (Fig. 1) expresses the degree of slip as a percentage of the AP diameter of the top of the lower vertebra. The second method is favored by most authors as it is more accurately reproducible. A simpler classification system divides spondylolisthesis into cases with translation of ≤50% (stable) and those with translation of >50% (unstable). Patients with higher grades of spondylolisthesis and higher slip angles, a measure of lumbosacral kyphosis, have a higher risk of progression [8].

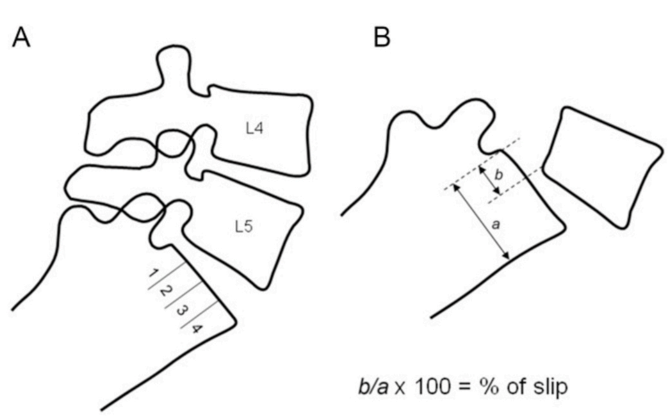

Fig. 1. Scheme of spondylolisthesis grading methods: (A) Meyerding, and (B) Taillard [8].

4. Management of spondylolisthesis

Conservative management is the mainstay for treating low grade spondylolisthesis. The classic indication for surgery is failure of a comprehensive conservative treatment for more than 6 months, and persistent progressive back pain [9]. Conservative management including regular physical therapy, home exercise, and NSAID. Addition for conservative management also include steroid injections and muscle relaxant. Bracing and lumbar extension exercise, range of motion and lumbar extension exercises, an strengthening of specific abdominal and lumbar muscles have shown improvement [5].

Several meta-analyses and reviews have tried to address the impact of non-operative management in degenerative spondylolisthesis, but more recent studies have reiterated the limited role of conservative management. The mainstay of surgical treatment of lumbar spinal stenosis with spondylolisthesis has always been decompressive laminectomy. However, for the last few decades, we have seen a substantial increase in the use of fusion surgery [10].

In an RCT, patients who received surgical treatments, including decompression, fusion without instrumentation, or fusion with instrumentation, had significantly greater improvements in Short Form-36 (SF-36) and Oswestry Disability Index (ODI) at 3 months compared to the non-operative treatment. Regarding the surgical technique, the addition of fusion to decompression is still up to debate. Even though there is a Level I and Level II evidence that favored the addition of fusion, there is also Level I evidence demonstrating non-significant result in adding fusion to decompression. Research has also shown minimally invasive surgery have similar outcome compare to open fusion, but with reduced cost and shorter time to recovery. It was also associated with less blood loss and shorter duration of hospitalization. It may give advantage in patients needing a 2-level fusion surgery [2].

4.1. *Conventional surgical technique*

The mainstay surgical treatment for lumbar spondylolisthesis are decompression, stabilization and fusion. Decompression surgery only without further instrumentation resulted in progression of the spinal slippage and increase in pain symptoms. Other studies also reported using posterior arthrodesis in-situ in children, although it was also resulted in pseudoarthrosis rates up to 40% which allowed progression of spondylolisthesis. Goals of reduction technique is to restore global spinal balance by correction of abnormal degree in lumbosacral joint [11,12].

Among the numerous fusion techniques that have been introduced, posterolateral fusion (PLF) or lumbar interbody fusion (LIF) are becoming the most popular fusion method for treatment of lumbar spondylolisthesis. Moreover, LIF has some advantages in restoration of the disc height and maintenance of lumbar lordosis compared to other fusion techniques. However, to achieve successful fusion, a three-dimensional fixation with pedicle screw is further needed [12].

A posterior pedicle screw fixation and interbody fusion are the gold standard for spinal stabilization that have been widely used by spine surgeons. Pedicle screws engage all spinal columns and can resist motion in all planes. This will preserve adjacent normal motion segment, prevent progression of deformity, and reduce symptoms of pain. Furthermore, pedicle screws can aid with reduction which may contribute in maintaining a normal sagittal balance. Fusion of posterior lumbar elements combined with stabilization with pedicle screws has been shown to reduce spinal instability and result in solid fusion up to 95% cases [13]. However, standard technique for pedicle screw placement require extensive soft tissue dissection to expose the entry point and to provide optimum orientation for screw trajectory. Consequently, it may be associated with severe bleeding, intense post-operative pain, and long hospitalization period [12,14,15].

4.2. Minimal invasive technique

Minimally invasive surgery is now widely used compared to standard open technique to reduce iatrogenic damage to adjacent structures. Recently, a percutaneous pedicle screw placement technique with image intensifier-guided has been introduced to avoid muscular trauma as in open surgery during screw placement. Moreover, reduction system that utilizes percutaneous pedicle screws have developed and applied in spondylolisthesis surgery [12,16].

4.2.1. Surgical technique of minimally invasive spondylolisthesis decompression, reduction and stabilization

A 3–4 cm paramedian longitudinal skin incision is made approximately 3 cm lateral to midline to perform unilateral spinal decompression and fusion cage placement. Paraspinal muscles are dissected along the spinous process to the articular process. The interlaminar space is exposed with the help of Caspar retractor. The disc and endplate cartilage are removed through an interlaminar approach. The bone graft-filled cage is then inserted to the empty disc space [12,16].

Other mini skin incisions are made for screw placements. A spinal needle is inserted through the deep fascia and advanced by the Wiltse intermuscular approach. Anteroposterior (AP) and lateral image intensifier views are used to confirm the position of the needle. As the needle tip is located at the medial border of the pedicle in the true AP view, the lateral view is used to assist advancement of the needle until it reaches posterior margin of the vertebral body. A guide wire is then inserted through the needle. The needle is removed and then tapering should be done to prepare the screw insertion until the junction between pedicle and vertebral body. A cannulated percutaneous long-arm pedicle screw is then advanced through the guide wire into the pedicle and vertebral body. Pedicle screws for the upper slipped vertebra are inserted with the wide-open rod passing space to reduce the slippage degree. Under image-intensifier, an adequately sized and pre-bend rod is placed in the percutaneous pedicle screw heads through a small incision made over the upper lumbar region. Rods are tightened with confirmation of the reduction in the slippage degree. Long arms of the screw are broken off and then wound irrigation and closure are performed [12,16]. The procedure is resumed in Fig. 2.

4.2.2. Surgical outcomes of minimally invasive percutaneous long arm pedicle screw fixation

He et al. [16] used percutaneous pedicle screw fixation with long-arm screw for spondylolisthesis reduction. The procedure comprises three stages, including external fixation, subcutaneous internal fixation, and deep muscle layer internal fixation. There were no significant differences of surgery time between this technique and open surgery. However, the MIS procedure had less intraoperative blood loss, shorter length of stay, and faster postoperative functional recovery. The short-term outcome was significantly better than that of the standard open surgery [16].

Study conducted by Park et al. [17] used minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) mono-segmental reduction in lumbar spondylolisthesis. This study used long tab type percutaneous screw system regarding its simplicity and similarity to conventional pedicle screw system, but easier for manipulation in the last step of surgery. This procedure is called “swing” technique based on its procedure, in which the entire percutaneous screw is swung back and forth for several times after placement of construction. This study includes only patients with Meyerding grade I or II. Swing technique resulted in better improvement of degree of spondylolisthesis and

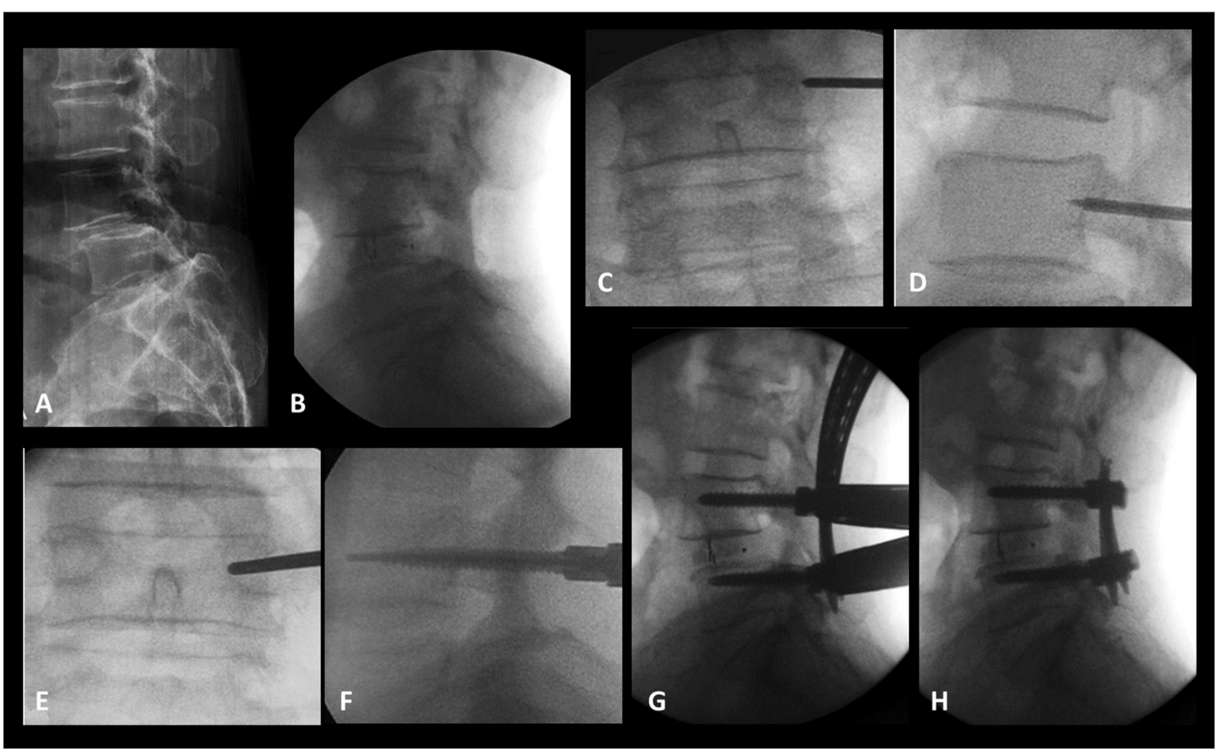

Fig. 2. Minimal invasive spondylolisthesis surgery. A. Pre-operative X-Ray shows anterior slippage of L4 with respect to L5 vertebrae. B. Decompression and posterior lumbar interbody fusion have done. Intervertebral disc height is restored with some reduction of the slippage degree. C. Needle insertion point at the lateral margin of the projection of pedicle axis on true AP view. D. The needle should be advanced parallel to the pedicle axis until it reaches the posterior margin of the vertebral body on the lateral view. E. AP image confirms needle tip placement on the medial margin of the pedicle. F. Screw insertion through the guide wire. G. Rod insertion. H. Complete slippage reduction is achieved after distraction and/or compression and final screw thightening [12,16].

reduction rate compared to conventional screw systems [17]. Other studies also showed successful procedure in high-grade spondylolisthesis [18].

A case report from Kulkarni et al. [19] performed MIS-TLIF in 40-year-old female with chronic claudication back pain in right L5 dermatomal with paresthesia diagnosed with spondyloptosis. MIS-TLIF using percutaneous pedicle screw-rod system was done. Reduction was achieved with improvement in ODI and VAS score. Some advantages in MIS-TLIF include minimal incision and exposure, which may be preferable in obese patients [19].

There are several instrument alternatives that may be used as reduction and fixation device in treatment of spondylolisthesis. There are pedicle screw/rods and threaded interbody cylinders, which are available as metallic cages or machined cadaveric cortical bone dowels. Metallic cages have sharper threads, although the geometrical configurations are relatively similar. Study from Çagli et al. [20] compared biomechanical stability using threaded bone dowels, threaded titanium cages, and pedicle screw/rods in management of in vitro model of Grade I lumbar spondylolisthesis. Pedicle screw/rods allow resistance of both angular and shear motion far better than interbody devices due to its rigid insertion. This may be explained from the fact that effectivity of threaded interbody cylinders (cages or dowels alone) is heavily dependent to integrity of remaining ligaments and annulus, compared to pedicle screw/rods that depend on bone. However, pedicle screw/rods and threaded interbody cylinders are affected by bone quality, which is supported from the findings in which lower bone mineral density (BMD) are correlated with greater ROM and NZ. The study concluded that pedicle screw/rods are biomechanically better than both cages or dowels alone [20].

Study conducted by Lengert et al. [21] compared lumbar high-grade spondylolisthesis reduction and maintenance overtime using longer pedicle screw (L4-S1) or shorter instrumentation (L5-S1). Radiographic evaluation to evaluate percentage slip using Talliard index showed decrease from 64% to 37% ($p = 0.0001$). Loss of reduction was observed in L5-S1 instrumentation, as much as from 19^{o} to 14^{o} compared with maintained reduction in L4-S1 instrumentation ($p = 0.006$). This study concluded that posterior L4-S1 fusion is better in long-term control of lordosis reduction compared with shorter instrumentation fusion [21]. Another study also showed that longer screw is associated with improvement in vertebral load distribution and it may decrease the mechanical stress on bone-screw interface [22].

The use of percutaneous long-arm pedicle screw allows reduction of spondylolisthesis possible with satisfactory outcome. Following insertion of the screw into the pedicle, the elongated U-shaped arm can be exposed outside the body, which may serve as a guiding function such as an extender. The study conducted by He et al. [16] showed significant improvement in VAS and ODI score with insertion of long-arm pedicle screw ($p < 0.05$) [16].

4.2.3. *Drawbacks of minimally invasive percutaneous long arm pedicle screw fixation*

The minimally invasive pedicle screw insertion is not without limitations. Although it is fluoroscopy guided, there is still risk of malposition and canal violation. The incidence of nerve injury during percutaneous pedicle screw placement is 0.5%. Post operative pain or discomfort may also develop due to the epidural hematoma which is cause by the blood oozing out from the bone that is trapped under the intact posterior tension band which leads to an increased pressure in the epidural space. However, this hematoma is eventually resolved. Other possible drawbacks that might occur later is the new onset of radicular pain due to instability pain related to the implant subsidence, migration, pseudoarthrosis, or new pain generators (i.e., fibrosis). Adjacent segment degeneration, screw prominence, and wound infection were also reported in some literatures [16].

5. Conclusion

The recently developed minimally invasive technique to reduce spondylolisthesis is a promising advance in spinal surgery. This technique is safe and feasible to use with lesser soft tissue dissection, blood loss, post-operative pain and length of hospitalization. Further research to reduce the financial burden to patients is needed especially for the application in developing countries.

Ethical approval

None. Because this paper is a literature review and not considered as human research. Thus, it does not typically require IRB review and approval.

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Author contribution

All authors contributed to data analysis, drafting or revising the article, have agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

Registration of research studies

Not required.

Consent

Not using patient in this review.

Disclaimer

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Declaration of competing interest

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