

Review Paper: Skipping Cross-links in Posterior Spine Surgery: A Review



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ABSTRACT

Background and Aim: Given the conflicting and unreliable evidence for using cross-links in posterior spine surgery, this review was conducted to highlight the different features and usefulness of these augmentation devices in spine surgeries.

Methods and Materials/Patients: After searching databases using specific keywords, the relevant articles were ultimately selected and evaluated.

Results: Biomechanically investigating the use of cross-links has not resulted in unanimous explanations for their effect. The site and direction of cross-links have been rarely investigated in the literature. Some studies recommended eliminating their application from clinical practice; nevertheless, these studies do not necessarily yield clinical benefits. Posterior spinal fixation with pedicle screws and without cross-links offers stability in all the planes in most clinical conditions.

Conclusion: Excluding the cross-links in posterior spine surgery may shorten the operation time and reduce hospital costs. Researchers have reported other problems for cross-links such as late pain, device failure, infections, device prominence, and pseudarthrosis which may be obliterated through the avoidance of their combination in a spinal construct; nevertheless, the results of animal models of the application of special cross-links in a degenerative disorder or deformity suggest that diagonal cross-links provide the highest stability of the construct if they are matched with a rod-only system or with transverse cross-link constructs resulting in a rectangular configuration.

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Highlights

- A review of the literature suggests that the necessity of cross-links has rarely been investigated in clinical settings.
- It was found that adding cross-links did not cause rotational instability in clinical practice.
- The use of cross-links in pedicle screw and rod instrumentation can be removed.
- Avoiding the use of cross-links shortens surgery time and decreases the total hospital cost.

Plain Language Summary

The efficacy of pedicle screw-rod system as spinal instrumentation has been verified. It is a preferred technique in posterior spine surgery because of its rigid 3-column fixation of the spinal elements. To enhance the stiffness of the device in the lateral and torsional axis, cross-links as transverse connectors were developed to supplement the bilateral pedicular systems. Given the existing controversial literature and the absence of consistent evidence on using cross-links in posterior spine surgery, we collected the different features and usefulness of these augmentation devices in spine surgery.

1. Introduction

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pinal instrumentation has developed in recent years. The verified efficacy of pedicle screw-rod systems in posterior spine surgery is due to their rigid three-column fixation of spinal elements [1-3].

The indications for single or multiple pedicle screw fixation include translational instability in spondylolisthesis, axial instability in tumors and fractures, mechanical pain in pseudarthrosis, and deformity in scoliosis and flatback syndrome [3, 4].

Different types of instruments have been used in different projects to increase the success rate of pedicle screw fixation in achieving long-lasting fusion. This type of spinal fixation significantly raises the sagittal plane stiffness without increasing torsional loading and lateral bending forces. In order to enhance the stiffness of the device in the lateral and torsional axes, cross-links were developed as transverse connectors to support bilateral pedicle systems [4].

Surgeons, however, insist on the need for using cross-links in the posterior instrumentation of spine surgery through inserting several pedicle screws, especially in patients with adolescent idiopathic scoliosis. Improvements in the construct stiffness are an advantage of cross-links, whereas their drawbacks include discomfort, higher costs and risk of pseudarthrosis [5, 6].

Given the challenging and unreliable results obtained for using cross-links in posterior spinal surgery, this review was conducted to highlight the different features and applications of these augmentation devices in spine surgery.

2. Methods and Materials/Patients

The keywords used for searching databases such as PubMed, Google Scholar, and Ovid included spine, instrumentation, pedicle screw, cross-links, scoliosis, deformity, trauma, torsional stability, configurations, and interbody fusion. Articles in languages other than English were excluded and those published before 2000 were included given the limited publications in this field. The relevant articles were selected and evaluated.

3. Results

The mechanical strength provided by instrumentation is crucial for the clinical success of spinal fusion. Numerous available pedicle screw-rod structures offer adequate strength and stability [7]. Despite their significant increase in the stiffness of the sagittal plane, these systems are vulnerable to instability under torsional loading and lateral bending. Cross-links can raise the torsional rigidity of bilateral rod systems [7] and their main consequence emerges under torsional loading [7]. A variety of designs and numbers of cross-links have been investigated in posterior spine fusion [8-10].



Cross-links were primarily planned to increase and maintain the stability of the coronal plane in long-segment scoliosis surgery [11-13]. They can increase axial stress loading, prevent lateral bending and rod migration, and minimize the total number of pedicle screws inserted in long-segment fixation [14-16].

Biomechanical studies have either supported or questioned the usefulness of cross-links [1, 2, 15]. Clinicians are also uncertain about practical requirements for cross-links and their number and position in constructs [17-19]. Moreover, the biomechanical investigations of using cross-links have not yielded consensus about their effects. The site and direction of cross-links have been also rarely addressed in the literature. Recommendations on how and where the cross-links should be clinically used remain unclear [20].

Length of fusion segments and cross-links

The factors affecting the biomechanical investigation include the project of diverse cross-links, the biological model used for analysis, and the construct's length [7, 21]. Investigating cross-links in the sagittal plane suggested no differences in their biomechanics and stability in flexion-extension testing, even if multiple consequences were perceived in lateral bending. There are no strong indications for the use of cross-links in short-segment lumbar fusion, rather than longer constructs in the thoracic or thoracolumbar segments [7-9].

Long-segment devices benefit from cross-links to reduce the torsional load over the rod which can create stress and correction loss [4]. Cross-links also resist lateral movements and increase the pull-out strength of long pedicle constructs, while some biomechanical studies appraising the variable outcomes of cross-links insertion [1, 5, 10, 11, 15, 16]. The cross-linking strategy can play a key role in the total rigidity of the construct. Alizadeh et al. (2013) reported the maximum stability, decreasing stress at the adjacent vertebral and instrument under different loading situations in long-segment fusion instruments [22]. The shape of cross-link had no role in short-segment instrumentations.

Increasing the number of cross-links inside a construct was reported to raise resistance to lateral bending and torsional loading [10-12]. Despite improvements in cross-links, spine specialists report instrument failures in long segment fusions in thoracic and thoracolumbar surgeries. Numerous common contrary outcomes are detected after long spine fusion, as well as adjacent segment disease, proximal or distal junctional kyphosis

generally crossways the thoracolumbar junction, and finally implant failure. Adjacent segment disease was reported 18.5% in long fusions compared with 5% in short fusions [21]. Distal kyphosis is more challenging than proximal kyphosis despite its lower rate of occurrence [23-25]. Sublaminar wires, hooks, and hybrid hook-pedicle screw constructs cannot efficiently prevent implant failures given their frequent use in the proximal or distal end of posterior fusions [26].

Number of cross-links

Surgeons tend to use single or multiple cross-links. Although there are no definite strategies, the tendency to integrate cross-links increases with a rise in the frequency of arthrodesis. Transverse connections are not free from erosion and device failures and can cause infections due to skin wounds [27]. High pseudarthrosis rates have been recommended in literature and cross-links endorsed for the reduced interaction area of fusions owing to implant overloading [28-30].

Biomechanical investigations of cross-links to determine an optimal position and direction for cross-links have reported no significant effects. The site and direction of cross-links have been rarely reported in the literature. How and where cross-links should be clinically used remains to be clarified [19].

The bending stiffness of the cadaveric lumbar spine was measured in terms of flexural, extensional, lateral, and axial rotation in pigs. Cross-links were found to significantly improve axial rotation stiffness, although flexural, extensional, and lateral stiffness did not increase. Using two cross-links was also found to significantly increase axial rotation stiffness compared with using one, whereas the site and direction of cross-links did not affect the stiffness [19, 20].

Configuration of cross-links

Compared with transverse type cross-links, their "X" configuration was reported to increase torsional stiffness [22]. Figure 1 shows a new pattern in which a cross-link passing through the base of the spinous process raises the mechanical strength in contrast to flexural loads and pull-out matched to conventional ones. Dick et al. (1997) reported insignificant increases in the flexional, extensional, lateral, and axial stiffness of instruments using cross-link constructs [9]. They also discovered a significant rise in torsional stiffness irrespective of the type of device using double cross-links with higher resistance to rotation compared with a single cross-link. The

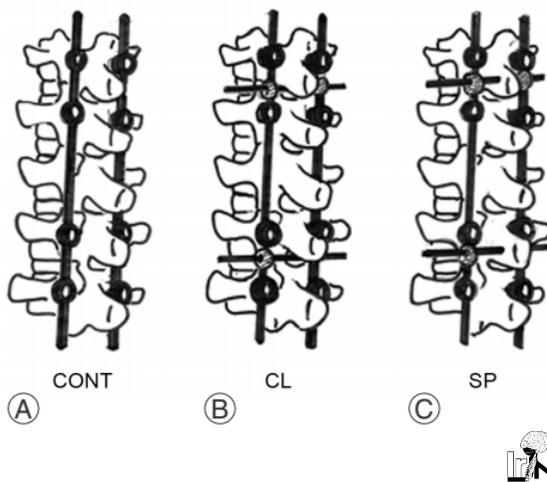


Figure 1. A schematic diagram of cross-link configurations evaluated by Nakajima et al. [35].

A: Un-cross-link control (CONT); B: Conventional cross-links; C: Cross-links passing through the base of the Spinous Processes (SP); *Reproduced with permission from the main source (Asian Spine Journal).

increased torsional stiffness provided using cross-links is the most essential in long segments wherever torsional forces cause cumulative dislocation and correction loss through the whole length of intervertebral rods. As in the case of all combinations of transverse connectors, pedicle screws ensure torsional stability against long thoracic or thoracolumbar instruments [11]. Cross-links also resist lateral transposition and raise the pull-out strength of screws by involving bilateral rod systems [31, 32]. The stability of a pair of diagonal cross-links was maximized under torsional loading when matched with rod-only controls or transverse cross-links [4, 5].

Conventional transverse cross-links were not significantly more stable than rod-only instruments, which is consistent with the findings obtained by Dick et al. (1997) and Korovessis et al. (2001), who attributed the effect of cross-links on torsional stiffness to their cross-sectional area [9, 32]. Compared to conventional cross-links, simpler and thinner tools such as 2-mm cross-links were inserted into the base of the spinous process in pigs [32, 33]. These novel cross-links passing through the spinous process base therefore provided a stronger structure under pull-out loading than did rod-only constructs without cross-links. The resistance of this upgraded cross-link configuration to instrument failures under flexural loading was also higher than that of conventional transverse cross-links (Figure 1) [33, 34].

The benefits of cross-links appear to be maximized by promoting surgical procedures, and they can help improve different spinal constructs. Dick et al. (1997) found that cross-link did not significantly increase the axial, flexural-extensional, and lateral stiffness of implants. However, they reported significant increases in torsional stiffness irrespective of the construct and two cross-links caused more resistance than a single cross-link [9]. The increase in torsional stiffness using cross-linking is crucial for long rather than short constructs.

Pedicle screws increase torsional stability in long thoracic fusions irrespective of the cross-links used [11, 12]; nevertheless cross-links counterattack lateral dislocation and raise the pull-out strength of screw by connecting bilateral implants [16]. The cross-sectional diameter of cross-links is associated with a rise in torsional stiffness [7, 32].

An animal model showed a significant increase in the original stiffness using the diagonal type cross-link to be associated with improvements in the energy consumed under pure torsional loading. The construct stability caused by the diagonal cross-links was significantly higher than that caused by rod-only controls or transverse cross-links with a quadrangular configuration [5].

Trauma and cross-links

Research suggests cross-links are not essential in severe traumatic spinal cord injuries in cases of long-segment posterior instrumentation, anterior reconstruction, and preserved rotational stability. Rises were reported in the stiffness of short-segment posterior instruments in a corpectomy model by adding one or two cross-links [33], although the cross-links did not return the standard stability. The authors also thoroughly recommended long-segment posterior pedicle screws and anterior reconstruction for re-establishing the baseline stability [33].

Thoracic spine originates stability because of the rib cage and therefore adding cross-links could be of insignificant value [33, 34]. The numerous benefits of eliminating cross-links include a decrease in the surgery duration, especially in cases of combined cross-links in the construct [34, 35]. Pedicle screw fixation of unstable thoracolumbar injuries is relatively new. The rotational and bending stiffness of pedicle screw fixation with zero, one, or two cross-links was investigated in thoracolumbar traumas [7-9]. The rotational stiffness of the two cross-link construct was significantly higher than that of the zero cross-link system at 2.5 and 3.5 degrees of rotation. The lateral bending stiffness of the two cross-link

systems was also higher than that of the zero cross-link system at all points of movement [7-9].

Deformity and cross-links

Compared with hook instrumentation, pedicle screw instrumentation can provide a strong fixation from the posterior arch to the vertebral body [36, 37].

Despite the controversial effect of pedicle screws on the growing spine, there is consensus over the need for minimizing the number of vertebrae in the fusion region of the pediatric spine to minimize the effect on the longitudinal growth of the immature spine [38-41]. Shortening the fixation region and decreasing the size of pedicles and the thickness of the cortical shell of the vertebral body in pediatric patients, most likely lead to reduced fixation strength and perhaps increase the risks of pedicle screw pull-out [42, 43], correction loss [44], crankshaft phenomenon [45] and quadrilateral shift [46]. Scoliosis Research Society reported implant-induced complications as approximately 1.5% in pediatric patients [47]. To increase the fixation stability, a cross-link is therefore inserted as an adjuvant implant between bilateral rods in posterior instrumentation constructs. Although a clinical study reported no need for using cross-links in spine surgeries [48], numerous biomechanical tests demonstrated that adding cross-links to bilateral rods locked to pedicle screws significantly increases the torsional stiffness of constructs [1, 2, 8, 10]. Compared with pedicle screw-only instrumentation, a single cross-link was found to cause significant decrease of 21% in the range of motion of instrumented vertebrae. Cross-links connecting bilateral rods can limit the axial translation of the total construct [15].

Surgeons continue to debate the need for cross-links in posterior spinal instrumentation constructs with segmental pedicle screws in adolescent idiopathic scoliosis. The benefits of cross-links include increased stiffness of constructs and their disadvantages are high costs, risk of late operative-site pain, and pseudarthrosis. Research suggests no differences in the maintenance of correction, SRS scores, and complications with or without cross-linking posterior segmental instrumentation in patients with adolescent idiopathic scoliosis over a 2-year follow-up. Longer follow-ups were therefore recommended [5, 7].

Interbody fusion and cross-links

In a spinal section fixed with posterior lumbar interbody fusion constructs, facetectomy causes a minimal rise in the range of motion and neutral zone in flexion-

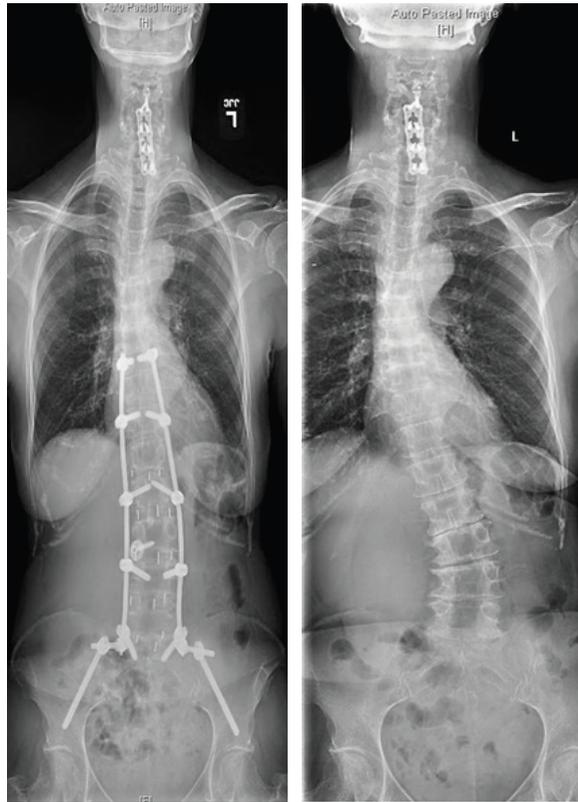


Figure 2. Two-year post-operative radiograph in a 62-year-old female with adult kyphoscoliosis deformity treated with interbody fusion, showing neutral alignment in coronal plane without cross-links placement [50].

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extension and lateral-bending, which are not influenced by adding cross-links. Even though the result of facetectomy is superior in axial rotation than in the bending planes, all variances are in a few tenths of a degree below this loading model. Cross-links cannot be therefore clinically supported based on these minor biomechanical alterations (Figure 2) [49-52].

Complications

Extensive investigations showed the complications of using pedicle screw-rod systems and cross-links to be associated with the hardware and include screw back-out, screw breaking, and system collapse as well as overlooking dural tears causing the cerebrospinal fluid leak, wound infections, and neurologic deficits [48-50].

Late durotomy and cerebrospinal fluid leak were reported as secondary to the compression of the dura by a low profile cross-link. Cross-links should be therefore positioned away from the dura. These rarely-occurring

complications should be, however, well prevented. After repairing the cerebrospinal fluid leak, the fusion field should be re-established [11].

Pedicle screw fixation was not the cause of the developmental retardation of the spinal canal in small children. Moreover, addition cross-links to screws and rods did not negatively affect the growth of the spinal canal. It is therefore recommended that cross-links be added to instrumentation to increase the fixation stability, especially in growing patients [52].

4. Conclusion

Several biomechanical trainings support the necessity of using cross-links in posterior spinal instrumentation. Although posterior pedicle screw fixation with cross-links improves the stability of all the planes, research suggests the use of cross-link can be removed from clinical work.

Avoiding the use of cross-links appears to shorten surgeries and decrease the total hospital cost. The problems of cross-links reported to include device failures, prominence of device, infection, pseudarthrosis and late pain can be solved by avoiding their application in spinal constructs.

In the case of using cross-links, especially in degenerative diseases and deformities, animal models suggest diagonal cross-link configurations provide the most stable constructs compared to rod-only systems and transverse cross-link constructs with rectangular configurations.

Ethical Considerations

Compliance with ethical guidelines

There is no animal or human research reported in this letter, there was no need for ethics board approval.

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Authors' contributions

Both authors equally contributed to preparing this article.

Conflict of interest

The author declared no conflict of interest.

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