

**Dynamic Stabilization in the Surgical Management of Painful Lumbar Spinal Disorders**

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**Study Design.** A literature review.

**Objective.** To evaluate the mechanisms of action and effectiveness of posterior dynamic stabilization devices in the management of painful spinal disorders.

**Summary of Background Data.** Dynamic stabilization may provide pain relief by altering the transmission of abnormal loads across the degenerated disc space.

**Methods.** A Medline search was conducted.

**Results.** Articles supporting abnormal load transmission across the disc space and clinical reviews of currently available posterior dynamic systems were included.

**Conclusions.** Posterior dynamic stabilization systems may provide benefit comparable to fusion techniques, but without the elimination of movement. Further study is required to determine optimal design and clinical indications.

**Key words:** dynamic stabilization, degenerative disc disease, lumbar spinal disorders, low back pain, motion preservation, lumbar fusion. *Spine* 2005;30:S68–S72

Current surgical management of the painful lumbar motion segment is imperfect. Improvements are necessary in the predictability of pain relief, the reduction of treatment related morbidities, and an overall improvement in the clinical success rates of pain reduction and functional improvement. Recent advances in fusion techniques have elevated arthrodesis rates, without an equivalent improvement in relief of pain.\(^1\) Fusion is intended to alleviate pain secondary to abnormal motion, or instability.\(^2\) Recent reports, however, have demonstrated relative success with implants that permit movement rather than eliminate it. These observations have promoted a more thorough understanding of alternate mechanisms that cause low back pain, particularly those centered on patterns of load transmission in the disc space.

Abnormal patterns of load transmission are recognized as a principal cause of osteoarthritic changes in other joints.\(^2\) Spinal osteoarthritic changes may be due to similar forces across the lumbar disc. Dynamic stabilization, or “soft stabilization,” systems seek to alter the mechanical loading of the motion segment by unloading the disc, without the loss of motion required by fusion surgery. The concept is particularly appealing with greater recognition of the negative effects of fusion on adjacent spinal segments and global functioning of the spine following surgery. Additionally, the concept may help explain the common clinical scenario in which back pain is primarily related to position or posture, rather than movement of the lumbar spine. The clinical application of this concept will be explored, along with the international experience to date, and potential future directions.

**Rationale for Dynamic Stabilization**

For two decades, the dominant surgical justification for fusing the painful motion segment has been the concept of instability.\(^4,5\) Yet, instability is difficult to define. When abnormal motion is present on flexion-extension radiographs, especially in the setting of spondylolisthesis, fusion seems an effective option.\(^6\) By this standard, however, relatively few patients with low back pain have overt subjective or objective evidence of instability.

Low back symptoms often implicate abnormal loading rather than motion as the primary source of pain. Many patients complain of postural or positional pain as a prevailing symptom.\(^7\) Radiographs of these patients often fail to demonstrate motion on dynamic studies. Furthermore, many patients with low back pain fail to improve following a successful lumbar fusion.\(^1,8\) These observations suggest that low back pain may have etiologies related to load, and successful treatments may exist beyond fusion.

Pain at a symptomatic motion segment may originate from the vertebral endplates, the disc annulus, vertebral periosteum, facet joints, and/or surrounding supportive soft tissue structures.\(^9\) As the lumbar spine ages, these structures undergo well-described degenerative changes, such as disc space dehydration and collapse, and corresponding facet arthropathy. The increased stiffness that accompanies these changes may further aggravate global spinal function, by diminishing sagittal balance and disrupting coronal and sagittal contour.\(^10,11\)

The pathologic changes within the disc space may result in abnormal transmission of load across the endplates. It has been well established that, in other weight-bearing joints, abnormal load transmissions result in degenerative changes, and the resultant pain may be diminished by a properly placed osteotomy.\(^5\) For example, in younger patients, alteration of the load transmission across a painful hip joint is often treated in this way. By comparing the role of the normal and degenerated disc on load transmission, we may see the same principles applied to the painful lumbar motion segment.
The normal disc consists of a homogeneous gel of collagen and proteoglycan. The normal disc is therefore isotropic, like a fluid-filled bag, a property that allows it to transmit load uniformly across the vertebral endplates. Importantly, this asset allows the disc to distribute equal loads across its surface regardless of position. In this way, flexion, extension, and lateral bending are all accommodated.

Disc degeneration alters the isotropic properties of the disc. The disc becomes nonhomogeneous, with areas of fragmented and condensed collagen, fluid and gas. Load transmission over the endplates, therefore, becomes uneven. Focal loading of the endplate cartilage and subchondral bony trabeculae can occur with certain positions, leading to endplate thinning and destruction. Since a clear-cut association exists between posture and load on the disc, it may follow that certain positions are more tolerable, and may limit pain.2,28 It is interesting to note that the most successful interbody fusions are associated with development of bone around the cage, increasing the surface area for load transmission. Without such bone, interbody devices may transmit enormous loads to the vertebral endplate. It is possible that the success of large interbody fusions is due to a favorable alteration of load transmission. Posterior stabilization systems may provide similar benefit by altering disc loads without the loss of movement. By creating a more normal loading pattern, dynamic stabilization may replicate the success of large volume interbody fusions, without the loss of movement.

Dynamic systems, therefore, may work by limiting movement to a zone or range where normal or near normal loading may occur or by preventing a spinal position where abnormal loading may occur.

Device History

Outside of North America, lumbar dynamic stabilization devices have been used for over a decade. Typically, these systems provide dynamic, or “soft” stabilization by providing a posterior tension band. This places the motion segment in extension while allowing limited movements in other planes. The Graf ligament system was one of the first such devices used. It consists of a posterior nonelastic band that serves as a ligament between two pedicle-based screws (Figure 1). The inventor, Henri Graf, thought that abnormal rotatory motion was responsible for the clinical effects of the Graf system. The device was primarily designed to control rotatory movement by locking the lumbar facets in the extended position. Limited flexion was allowed within the range of normal movement. By providing posterior tensioning, the system probably unloads the anterior disc and may redistribute the load transmission of the painful disc. Although widely used, the clinical effects of the Graf system have not been rigorously studied. Some analyses, however, have demonstrated clinical success of the Graf ligamentoplasty similar to fusion procedures. In two separate studies, clinical rates of excellent to good outcomes were in the 75% range with 2-year follow-up. It is recommended by the authors that the device be used in younger patients with adequate lumbosacral musculature, and in whom facet arthropathy is minimal. A prospective study of 88 patients by Konno and Kikuchi with low-grade spondylolisthesis, application of the Graf system seemed...
to diminish low back pain complaints as compared to decompression alone at 4 years. The device has also been associated with an increase in lateral recess stenosis due to abutment of the facets in extension, infolding of the ligamentum flavum, and reduction of the neural foramen. This effect was primarily due to the segmental lordosis associated with its application and resulted in some early surgical complications.

The Dynesys system (Zimmer Spine, Warsaw, IN) includes a design that provides both controlled flexion and extension by combining a tension band with a plastic tube, which resides between pedicle screws (Figure 2). In flexion, motion is controlled by tension on the band, while during extension the plastic cylindrical tubes act as a partially compressible spacer, thereby allowing limited extension. Indeed, these plastic cylinders can be partially weight bearing in extension. In order to function properly, application of the Dynesys device must follow careful technical guidelines. Inappropriately long plastic spacers, for example, may cause a focal kyphosis, a scenario that has been associated with poor outcomes.

The Dynesys system may have some advantage over pure band-like devices in that it provides some protection against compression of the posterior anulus, a structure known to contribute to painful load bearing. Biomechanical testing of in vitro reconstructed human cadaveric spines indicates that Dynesys provides 1° to 3° of greater movement at L3-L4 than rigid fixation in both flexion and extension. Compared with the intact spine, the implant permits similar degrees of extension but restricts flexion by 30%. Stoll et al reported on a multicenter experience with 83 consecutive patients, indicating an overall improvement in the Oswestry scores from 54 to 23. Grob et al recently reported a retrospective series of 31 patients followed over 2 years implanted with the Dynesys device. Although 67% of patients reported improvement in back pain, overall improvement in quality of life was only 50%, and 19% required reoperation in the follow-up period. The authors note that these rates compare favorably with fusion, although randomization was not performed. The device is currently undergoing evaluation by the Food and Drug Administration in the United States.

Other devices have sought to improve on these early designs, including the Leeds-Keio ligamentoplasty for spondylolisthesis, and the FASS (fulcrum-assisted soft stabilization) system. The latter uses a slightly anteriorly placed flexible fulcrum to maintain distraction of the posterior anulus during extension. This allows unloading of the disc space while still providing motion.

The Leeds-Keio device was studied by Muchida et al, who reported a reduction of back and leg pain with use of the device comparable to fusion in spondylolisthesis. Despite these generally favorable results, however, it should be noted that these studies are not of sufficient size or caliber to provide convincing data regarding the benefit of dynamic stabilization in the management of low back pain. Furthermore, no motion device is cleared for use in the United States at present.
Clinical Application of Dynamic Devices

Posterior dynamic lumbar spinal implants may have advantages over rigid systems in both fusion and nonfusion applications. By allowing bone graft in the interbody space to experience increased compressive loads during flexion, these devices may increase the likelihood of bony fusion across the interbody space (Wolfe’s Law). It is also likely that these devices would be eventually used as stand alone devices without arthrodesis. Under these circumstances, the device would provide stabilization across the motion segment without complete elimination of movement.

To function properly, these devices need to work in harmony with intact soft tissue supporting structures of the motion segment. Ideally, therefore, they would be implanted with minimal damage to the muscular and ligamentous structures that participate in normal spinal motion. At present, surgical implantation of dynamic stabilization devices is very invasive, with resulting disruption of the muscle and ligamentous structures. It is well recognized that these soft tissue structures play an important role in normal spinal movement, balance, and load transmission. Over time, these devices would ideally need the natural support of muscles and ligaments to function. Fortunately, advances in the surgical implantation of fusion-related devices, such as interbody cages, rods, and screws, have provided minimally invasive techniques. These techniques are far less disruptive of these supporting structures and are associated with faster recovery times. Optimal performance of dynamic devices would seem likely to result from a coupling of these minimally invasive techniques with the implant itself. Indeed, minimally invasive surgical techniques may be much more beneficial when used with motion-sparing devices than with fusion in long-term results.

Special challenges exist with regard to the long-term tolerance of dynamic implants with regard to the screwbone interface, as well as the fatigueability of the composite materials. Cyclical loading and unloading of the device as a consequence of daily physical activities may cause screw loosening, or implant breakage. Reports of screw loosening in the Dynesys system experience suggest that progress needs to be made in this area.41

Other motion-preserving devices, discussed elsewhere, may be placed between the spinous processes.47 Posterior pedicle-based devices, such as those described here, will probably be positioned along procedures involving larger decompressions, or those involving multi-level mild degrees of spondylolisthesis and/or anterior loss of height.

Conclusion

Dynamic stabilization systems have theoretical advantages over rigid spinal implants. They may allow similar or improved patient outcomes compared with fusions in patients in whom disc load characteristics represent a modifiable solution over the sagittal plane of the vertebral endplates. Some design features must be addressed, as well as placement of the devices with preservation of the surrounding spinal structures. Ultimately, a well-designed system would need to prove its clinical effectiveness in a well-designed prospective randomized clinical trial.

Key Points

- Dynamic stabilization systems have reported rates of clinical benefit comparable to fusion in a few small clinical series.
- Abnormal load transmission across the degenerated disc space may be a source of postural low back pain.
- Dynamic stabilization may alter the load transmission across the disc space into a zone of diminished pain generation while allowing limited motion.

References


