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Minimally-invasive posterior lumbar stabilization for degenerative low back pain and sciatica. A review

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ABSTRACT

The most diffused surgical techniques for stabilization of the painful degenerated and instable lumbar spine, represented by transpedicular screws and rods instrumentation with or without interbody cages or disk replacements, require widely open and/or difficult and poorly anatomical accesses. However, such surgical techniques and approaches, although still considered "standard of care", are burdened by high costs, long recovery times and several potential complications. Hence the effort to open new minimally-invasive surgical approaches to eliminate painful abnormal motion. The surgical and radiological communities are exploring, since more than a decade, alternative, minimally-invasive or even percutaneous techniques to fuse and lock an instable lumbar segment. Another promising line of research is represented by the so-called dynamic stabilization (non-fusion or motion preservation back surgery), which aims to provide stabilization to the lumbar spinal units (SUs), while maintaining their mobility and function. Risk of potential complications of traditional fusion methods (infection, CSF leaks, harvest site pain, instrumentation failure) are reduced, particularly transitional disease (i.e., the biomechanical stresses imposed on the adjacent segments, resulting in delayed degenerative changes in adjacent facet joints and discs). Dynamic stabilization modifies the distribution of loads within the SU, moving them away from sensitive (painful) areas of the SU. Basic biomechanics of the SU will be discussed, to clarify the mode of action of the different posterior stabilization devices. Most devices are minimally invasive or percutaneous, thus accessible to radiologists' interventional practice. Devices will be described, together with indications for patient selection, surgical approaches and possible complications.

1. Introduction

The last decades have seen a growing trend in use of minimally invasive techniques in spine surgery for the degenerated lumbar spine. Patients prefer such techniques because they reduce recovery times, yield less morbidity, and provide cosmetic benefits, and availability of Internet access to the medical consumer have increased the public demand for these procedures. Due to a low rate of complications, minimal soft tissue trauma, and reduced blood loss, more spine procedures are being performed in this manner, entailing shorter hospital stays, often on an outpatient basis. Also growing is the relevance of the epidemiology of low back pain (LBP) related the degenerative modifications of the lumbar spine, particularly in the aging population. LBP is a leading cause of chronic disability and psychological distress. In Europe, estimates of the lifetime prevalence of back pain range from 60% to 90% [1–3]. Back pain can be a sign of degenerative segmental instability, defined as "an abnormal response to applied loads, characterized by motion in motion segments beyond normal constraints" by the American Academy of Orthopedic Surgeons [4–6]. Motion in degenerated joints (i.e., beyond the normal limits of the joint itself) generates pain; eliminating abnormal motion seems to eliminate pain. Therefore, surgical spinal fusion (locking of two or more vertebrae as a single unit) with or without instrumentation has been the mainstay of surgical approaches for these forms of LBP. However, conventional fusion methods entail several potential complications (e.g., infection, cerebrospinal fluid leaks, harvest-site pain, instrumentation failure). Hence the effort to open new minimally-invasive surgical approaches to eliminate painful abnormal motion. Anatomically the most directly and easily accessible is the posterior one, and such corridor have been developed utilizing the interspinous space for X-STOP (see ahead) placement to treat lumbar stenosis in a minimally invasive fashion. The attention of biomechanics experts and spine surgeons has been focused

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mainly on the posterior structures of the spine, facets, and spinous processes, for two main reasons: (i) these structures are readily accessible by a minimally invasive approach and (ii) actions upon them determined by different devices can profoundly modify the functional behavior of the SU.

Posterior structures of the spine can be utilized by the spine surgeon in an attempt to obtain fusion at the instable level/s while at the same time minimizing openness of access corridors, post-operative paravertebral and epidural scarring, amount and size of hardware, costs and so on. Highly instable situations may still require fusion, although fusion techniques may increase the biomechanical stresses imposed on the adjacent segments, resulting in overload and early degenerative changes in adjacent facet joints and disks [7–11]. These issues have led to attempts to develop new motion-preservation technologies for the surgical treatment of spinal instability, commonly referred to as "dynamic stabilization". Dynamic stabilization has been defined as "a system that would alter favorably the movement and load transmission of a spinal motion segment, without the intention of fusion of the segment" [12]. Dynamic stabilization (or "soft stabilization") is intended to restrict motion in the direction or plane that produces pain ("painful motion"), thereby allowing a full range of motion. Dynamic stabilization techniques introduce a more gradual, intermediate therapeutic step between abnormal movement of the spinal unit (SU) (instability) and total absence of movement (fusion). The most significant advances in dynamic stabilization techniques were made in the past 10–15 years.

The combination of preservation of motion and minimal surgical invasiveness seems to be opening a new era in the surgery of symptomatic degenerative spine instability.

2. Historical notes

In 1937 Williams [13,14] first recognized the principle of distraction in his conservative treatment of lumbosacral disabilities, by maintaining a posture of flexion to correct the intervertebral subluxation and the narrowing of the foramina. In his anatomopathological studies he emphasized the role of intervertebral disk degeneration in priming lumbar and radicular pain. He also showed radiographic evidence of the widening of the intervertebral foramen in flexion of the lumbar spine.

In 1943 Breck and Basom [15] introduced the surgical concept of maintaining a fixed distraction in flexion of the lumbar spine, through the use of interspinous bone blocks. The Authors proposed a surgical arthrodesis in flexion of the interspinous space by means of a bone graft, defined by the Authors themselves as "mortised interspinous bone block", harvested from tibia or iliac crest, with the aim to relieve zygapophysial overload and to widen the neural foramina. This paper opened the way to surgery of the interspinous space.

Knowles in 1954 first designed and patented a metallic device for use as an interspinous distractor, with the aim of a minimally invasive approach to the degenerated lumbar spine. Knowles' basic concept was that unloading the lumbar structures could reverse the degenerative process and prime regeneration.

Knowles approach was not accepted by the surgical community until the eighties, when interspinous prostheses were proposed by French Authors, Sénégas [16] in 1988 and Bronsard in 1989. Bronsard's proposal was that of a prosthesis implanted between the vertebral spinous processes with locking suspension. It consists of a flat, semi-elastic braid and one or more small pads made of the same material as the braid. In the patent description is stated that "The invention is used in particular for straightening the vertebrae in order to combat lordosis". Bronsard first introduced the concept of using elastic material, acting as a shock absorber.

Sénégas, such as Knowles, was convinced that his "titanium interspinous blocker" could reverse degeneration of the spinal unit. Extended clinical experience was developed in the nineties, and in 2000 Sénégas released the final version of the device, still in use nowadays and made of polyetheretherketone (PEEK) (see ahead) [17,18].

In the same year more devices were developed based on the elastic principle of shock absorbing, the DIAM (see ahead) in particular could gain a wide success in the opinion and use of spine surgeons. But the real diffusion of interspinous devices was due to the invention of Zuchermann [19], an innovative device really minimally invasive and the first one totally respecting local anatomy, with regard in particular for the supraspinous ligament (see ahead for description of the device).

The final step in the evolution of such devices is represented by the percutaneous ones, among them the first having been the Aperius produced by Kyphon (now Medtronic). The device is made of titanium, while the second one, the InSpace proposed by Synthes, is made of PEEK.

More recently we observed a return to the origins, with the appearance on the market of interspinous spacers giving, at the same time of a distraction of the space and modification of loads in the spinal unit, the possibility of a associating a rigid arthrodesis (posterior fusion).

3. Basic biomechanics

The basic functional SU is the smallest physiological unit of motion of the spine. It is therefore termed a "motion segment". It consists of two adjacent vertebrae, the disk, and all the connecting ligaments. Individual motion segments contribute to the total motion of the spine. In flexion and extension, muscles apply a bending moment to the SU. During flexion of the lumbar spine, the total motion obtained (modification of posture from neutral to flexion) is the sum of the modifications obtained at the level of each single component of the SU, i.e., a decrease of the anterior disk height and a widening of interspinous space (angle between the spinous processes, which are stretched and moved apart). The supraspinous ligament is the structure limiting flexion more effectively. The opposite happens in extension, with an increase in the anterior disk height and closing of the interspinous space.

The neutral zone (NZ) is the position of the SU in which a small bending moment can result in a large movement (i.e., a large change in the angles between the two vertebrae). In a normal SU, the center of the NZ corresponds to the middle position between flexion and extension. A small moment is required to start flexion (or extension). However, with a progressive increase in the movement it becomes increasingly harder to obtain new flexion (or extension). The NZ is a measure of the laxity of the SU, and it widens in the presence of instability. Pathological widening of the NZ allows exaggerated movements, which in turn require a large amount of energy for return to the neutral state. Dynamic devices aim to reduce the NZ.

The instantaneous center of rotation (ICR) corresponds to the point at which, if load is applied, no bending occurs. It is defined as "instantaneous" because it can change at every instant during different types of movements. Predicting the ICR in structures as complex as the SU is difficult. The ICR changes with different movements and these changes become more unpredictable in the presence of instability. More often, in a healthy SU, in the standing, inactive position, the ICR is located posterior to the center of the disk, just above the inferior endplate (corresponding approximately to the center of gravity). It moves in flexion–extension, and the variability is considerable. There are no simple rules to predict