A Review Paper

Advances in Technology and Surgical Technique in Spine Surgery

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Abstract

This comprehensive review article encompasses a broad variety of topics within the spinal literature and includes an update on the latest technology and techniques for the spine.

In recent years, a spine surgery revolution has resulted in new technology and techniques being used to improve functional and long-term outcomes. These advances have led to decreased intraoperative blood loss, decreased postoperative pain, earlier return of and better functional status, improved long-term outcomes, and increased patient satisfaction. Newer techniques and innovations include total disc replacement, interbody devices, thoracic pedicle screws, bone graft extenders (eg, demineralized bone matrix [DBM]), and bone graft substitutes, including bone morphogenetic protein 2 (BMP-2) and osteogenic protein 1 (OP-1 or BMP-7). Techniques described in this article include intradiscal electrothermal annuloplasty (IDET); microendoscopic, laparoscopic, and thoracoscopic approaches; and vertebral body fracture treatment with both kyphoplasty and vertebroplasty.

Cervical Spine Disease

Cervical Disc Degeneration

Cervical disc degeneration, which is less common than lumbar disc degeneration, often results in chronic neck pain. Conservative treatment with nonsteroidal anti-inflammatory drugs (NSAIDs), steroids, bed rest, and traction should be initiated first, as surgery for neck pain results in less predicable outcomes and should be avoided if possible.

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After conservative treatments for cervical disc disease have been exhausted, other avenues of therapy can be explored. In addition to spinal fusion, there are several therapeutic options for treating cervical degenerative disc disease.

Cervical intervertebral disc replacements, which have had some degree of success, have become increasingly popular. The procedure has a longer history in Europe, but trials are being conducted at several centers in the United States; the first artificial cervical disc [Medtronic's Prestige disc] for treatment of cervical degenerative disc disease was approved by the FDA in July 2007. As with lumbar intervertebral disc replacements, the goal of the procedure is to maintain or restore motion in the cervical spine rather than perform anterior cervical discectomy and fusion (ACDF) with its possibilities of decreasing motion and accelerating adjacent-level degeneration. McAfee and colleagues[1] reported that 67% of patients showed adjacent-level degeneration after ACDF, and 10% of these patients required a second surgical procedure to address the adjacent level. Cervical intervertebral disc replacements have an advantage over ACDFs because they preserve motion and normal kinematics between 2 vertebrae. Biomechanical testing by Goffin and colleagues[2] showed preserved range of motion (ROM) at the level of implant with this technique. In a 2-year follow-up study, Bryan[3] demonstrated good to excellent results in a majority of patients both radiographically and clinically, and Goffin and colleagues[2] reported 64% good to excellent results. The latter authors also reported that, in a minority of patients, spontaneous fusion of the replaced level occurred with similarly good results. Unfortunately, rare catastrophic failure of the replacement with dislocation of the implant has been described.[4] Anterior displacement can result in swallowing difficulties and airway obstruction. Posterior displacement into the spinal canal can also occur, leading to paralysis and even death. In addition, the possibility of long-term wear debris and osteolysis with associated implant failure similar to that seen with joint replacements (hip, knee) remains a potential concern. Although cervical disc replacements may provide long-lasting good to excellent results, the procedure it aims to replace, single-level ACDF, has a 97% success rate. Therefore, before cervical disc replacement technology is embraced, a well-designed clinical trial must demonstrate the outcomes of the newer procedure to be superior to, or at least as good as, a highly successful and time-honored procedure with an excellent track record.[5]

Regarding the cervical spine, there has been much interest in creating hardware fusion devices that are resorbable by the body. ACDF is the most common surgical procedure

performed in the cervical spine. When performing this procedure, many surgeons also apply a metal plate with screws to provide immediate stability to the construct to increase the fusion rate and to decrease the need for postoperative external braces like a halo vest or collar. Once bony fusion has occurred, the implants serve no other purpose. We know that implants placed in other areas of the body cause a rise in serum and urine levels of the metal ions used. The long-term effects of these circulating ions have yet to be determined and completely understood. Newer implants are being designed with bioabsorbable materials. Anterior cervical screws made of hydroxyapatite and calcium phosphate and plates made of a poly(L-lactic acid) mesh have been used instead of traditional titanium and stainless steel implants. These absorbable implants provide enough stability to increase fusion rates. Breakdown and resorption of these products occur after 6 weeks, the point at which bony fusion with autograft tends to occur. Kuribayashi and Matsuda[6] and Vaccaro and colleagues[7] conducted retrospective analyses of these resorbable implants. Fusion rates ranged from 71% to 77% at 1 year. These studies suggest promise for such instrumentation devices.

Cervical Spondylotic Myelopathy

Cervical laminoplasty as a surgical treatment option for cervical spondylosis with myelopathy is an alternative to a laminectomy alone or with fusion. Cervical laminoplasty, a spinal-canal-expansive operation without fusion performed with the hope of preservation of more cervical motion, was developed in Japan to decrease the high incidence of the postlaminectomy kyphotic deformities encountered with laminectomy alone. Ratliff and Cooper,[8] in a meta-analysis of the English-language literature on laminoplasty, reviewed 71 reports involving more than 2000 patients. They assessed neurologic outcome, change in ROM, development of spinal deformity, and complications. All studies were retrospective, uncontrolled, nonrandomized case series. Forty-one of these 71 series provided postoperative recovery rate data in which the Japanese Orthopaedic Association Scale was used for assessing myelopathy. Mean recovery rate was 55% (range, 20%-80%). The authors of 23 papers provided data on the percentage of patients improving (mean, ~80%). There was no difference in neurologic outcome on the basis of the different laminoplasty techniques or when laminoplasty was compared with laminectomy. There was postlaminoplasty worsening of cervical alignment in approximately 35% of patients and with development of postoperative kyphosis in approximately 10% of patients who underwent long-term follow-up review. Cervical ROM decreased substantially after laminoplasty (mean decrease, 50%; range, 17%-80%). The authors of studies with long-term follow-ups found that there was progressive loss of cervical ROM, and final ROM was similar to that seen in patients who had undergone laminectomy and fusion. In their review of the laminectomy literature, the authors could not confirm that presence of postlaminectomy membrane caused clinically significant deterioration of neurologic function. Postoperative complications differed substantially among series. In only 7 articles did the writers quantify the rates of postoperative axial neck pain (range, 6%-60%). In the 12 articles in which C5 nerve root dysfunction was reported, this complication developed in approximately 8% of study patients. The paper concluded that the literature has yet to support the purported benefits of laminoplasty. Neurologic outcome and change in spinal alignment are similar after laminectomy and laminoplasty. Patients treated with laminoplasty develop progressive limitation of cervical ROM, similar to that seen after laminectomy and fusion.

Other treatments for cervical spine myelopathy are ACDF and laminforaminotomy. ACDF as a therapeutic option has the best outcome when the pathology is limited to 1 level (a fusion rate of 96% is expected). ACDF fusion rate declines as the number of fused levels increases (only 75% for 2-level ACDF, 56% for 3-level ACDF). Augmentation with plates can improve these percentages by up to 11.8%.[9] Laminoforaminotomy involves a posterior approach to remove disc herniations or spurs causing the neurologic symptoms. The procedure is minimally invasive and effective in relieving radiculopathy without the need for spinal fusion. Complications such as tracheal edema, esophageal dysfunction, and stroke can also be avoided.[10] The disadvantages of laminoforaminotomy, which result from using a posterior approach, are paraspinous muscle dissection, postoperative axial neck pain, potential instability requiring fusion, and subsequent deformity.[11]

Lumbar Spine Disease

Surgical management of lumbar spinal conditions has also evolved considerably, leading to advances in spine surgery, including an increase in minimally invasive surgery applications (eg, IDET); vertebral body augmentation (eg, kyphoplasty, vertebroplasty); bone graft substitutes and extenders (eg, DBM, BMP); and, most recently, total lumbar disc replacements.

Lumbar Disc Degeneration

Lumbar disc degeneration can be a difficult diagnosis, partly because of controversies surrounding some diagnostic modalities (eg, discography). The initial approach to this debilitating condition should be conservative treatment; if that fails, more aggressive measures can be explored. For cases refractory to conservative treatment, a variety of surgical solutions can be used.

IDET is a minimally invasive outpatient surgical procedure developed and used over the past several years to manage patients with chronic low back pain caused by intervertebral disc disruption (eg, annular tears, small disc herniations). A small heating probe is percutaneously inserted into the intervertebral disc and fluoroscopically navigated to the potentially painful annular tear. The coil is then heated to a desired temperature in an effort to denature collagen, ablate nociceptive fibers, and modulate inflammatory processes. A randomized prospective trial by

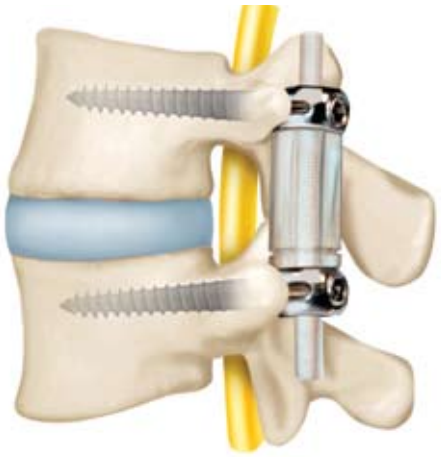

Figure 1. The Dynesys® Dynamic Stabilization System. Photo courtesy of Zimmer Spine. Used with permission.

Pauza and colleagues[12] found more than 75% pain relief in 50% of the patient population after IDET. Freedman and colleagues[13] and Saal and Saal[14] reported a failure rate of 50% in patients receiving IDET therapy at 2-year follow-up. Overall, IDET may be used in certain patients with unrelenting painful internal disc disruption after failing at least 6 months of conservative management.

Spinal fusion can also be used to treat lumbar disc degeneration. Although several new fusion techniques have been developed, such as 360° circumferential fusion, posterior lumbar interbody fusion, and anterior lumbar interbody fusion, the Swedish Lumbar Spine Study Group found no significant advantage of using one technique over another.[15] Whichever technique is used, the basic goal is to obtain solid bony fusion between the vertebrae of concern. This fusion is accomplished by attaching bone and/or bone extenders and substitutes to the spine through either an anterior approach (interbody) and/or a posterior approach (interbody and intertransverse) with or without use of hardware. Fusing the spine is intended to decrease back pain by limiting the motion at a painful motion segment. Unfortunately, lumbar fusions carry an increased risk for adjacent-level degeneration and the possible need for future surgical intervention. According to another large, well-designed study conducted by the Swedish Lumbar Spine Study Group, at 2 years after a lumbar spinal fusion, 63% of patients reported good or excellent results in terms of pain relief, decreased disability, overall increased function, and work return.[16]

This successful procedure can involve several approaches or treatment options, including anterior approach only, posterior approach only, and combined anterior–posterior approach. The procedure can be performed with or without instrumentation. With instrumented approaches, interbody devices or pedicle screws and rods can be used. Allograft, autograft, DBM, and BMP are all viable options, and their use typically depends on surgeon experience and training. With so many options, it is difficult to determine the best approach and fusion option. It is still agreed that iliac crest bone graft (ICBG) is the gold standard for fusion. If graft volume is determined to be insufficient, it can be augmented with either DBM or BMP. Although there is a lack of current studies proving the efficacy of bone graft substitutes, in the future these products may eliminate use of ICBG, its potential complications, and postoperative pain.

Compared with the traditional open procedures, anterior laparoscopic approaches to the lumbar spine are increasing in use mainly because of decreased postoperative pain, shorter hospitalization, and decreased associated blood loss.[17,18] Although there are potential advantages to laparoscopic surgery, several authors have reported similar postoperative narcotic use, increased hospital costs, and more intraoperative complications, including retrograde ejaculation.[19,20]

Lumbar intervertebral disc replacement is emerging as a treatment option for degenerative disc disease. This procedure has an extensive track record in Europe and is now approved by the US Food and Drug Administration. Throughout the world, a growing body of clinical research supports its efficacy. Lumbar intervertebral disc replacement is similar in principle to other types of joint replacements in that the damaged and painful joint is removed and replaced with a movable artificial joint. In the lumbar spine, the goal is to remove the damaged, painful intervertebral disc and replace it with a metal-and-plastic implant designed to provide motion similar to that provided by a normal intervertebral disc.

The theoretical advantage of lumbar disc replacement (vs spinal fusion) is 2-fold. First, the replaced disc permits and restores motion at the operated degenerated level. Second, the prosthesis decreases transfer stresses to adjacent levels, potentially protecting them from accelerated segmental degeneration. Thus, the goals of the lumbar intervertebral disc replacement are to achieve the same pain reduction that spinal fusion provides and to reduce potential long-term complications. Although extensively used in Europe, this promising advancement for patients with low back pain raises certain concerns, including the potential for implant displacement, wear debris, and the need for future revision surgery. McAfee and colleagues[21] conducted the first prospective, randomized study showing improvement in functional outcome measures, with disc arthroplasty mainly used to treat mechanical back pain and achieving successful results comparable to those achieved with lumbar fusion-interbody fusion cage and BMP or interbody autograft and pedicle screw instrumentation.

Another alternative to spinal fusion for treating degenerative disc disease is posterior motion preservation devices. One such device, the Dynesys® Dynamic Stabilization System (Zimmer Spine, Minneapolis, Minn) is currently 510(k) cleared by the FDA for use in the US as an adjunct to fusion in the lumbar spine. Dynesys consists of titanium pedicle screws connected by an elastic compound that controls motion in all planes (Figure 1). Dynesys is an attractive option because it approximates the physiologic motion of the spine better than fusion does while retaining stability.[22]

Compression Fractures of the Lumbar Spine

Kyphoplasty and vertebroplasty are minimally invasive percutaneous surgical procedures used in the management

of vertebral body compression fractures arising from osteoporosis or tumors. The goal of these procedures is to provide vertebral body stability to reduce pain caused by the fracture. This stability is achieved by placing various materials, such as polymethylmethacralate (PMMA), or bone cement, into the vertebral body through a cannula (Figure 2). Vertebral bone is stabilized, which may even partially restore the vertebral body height lost as a result of the compression fracture. It has been reported that 67% to 100% of patients receive good or excellent pain relief almost immediately after the procedure.[23] Vertebral height is partially restored in a majority of patients. The rare complications associated with the procedure include potential cement extrusion from the vertebral body into the venous system and spinal canal with potentially devastating results.[23]

Bone Graft Substitutes

Spinal fusion remains a common means of achieving stability and pain relief in spinal surgery. Methods for obtaining adequate fusion involve decortication of the host bone and application of grafting material. Autologous bone remains the gold standard for spinal fusion procedures, as it has 3 important properties (osteogenic cells, osteoconductive structure, osteoinductive matrix) that encourage effective bone healing leading to solid fusion. However, autologous bone harvest has a high rate of donor-site morbidity, and additional operative time is needed to harvest the bone. Thus, for the application in spinal surgery, intensive efforts have been directed toward developing alternative substances (eg, DBM, BMP) to replace or supplement autologous bone.

DBM has been available for approximately 10 years and is a popular form of allograft processing (DBM is available commercially as Grafton [Osteotech, Eatontown, NJ] bone matrix). DBM is prepared through an acid extraction technique that results in decalcification of cortical bone, leaving collagen, noncollagenous proteins, and growth factors. It can be processed into putty, gel, or a flexible sheet and can be applied along with autograft bone into a spinal fusion composite. It is mostly osteoinductive and osteoconductive and is not used alone. DBM is a bone graft extender (not a substitute) intended to be used to achieve higher fusion rates with less autologous graft.

There has been a recent explosion in basic science research in and clinical applications of recombinant human growth factors or BMPs. Boden and colleagues[24] demonstrated increased fusion rates with bovine BMP (100%) versus autograft (62%) in a rabbit posterolateral intertransverse fusion model. BMP-2 and OP-1 (BMP-7) have been shown to induce and form new bone growth, and several products are being tested. Extensive animal testing has been undertaken, and human trials are under way. BMP-2 has been used inside interbody titanium fusion cages with great results (solid fusions in 11 of 11 patients in a pilot study). Although results are overwhelmingly positive and may obviate the need to harvest autologous bone graft, it is important to note that BMP use adds substantial cost to an already expensive fusion procedure. Such use needs to be demonstrated as cost-effective before being embraced by the spine care community. Development of bone graft substitutes and extenders is one of the most exciting and sought-after areas of research in spine surgery.

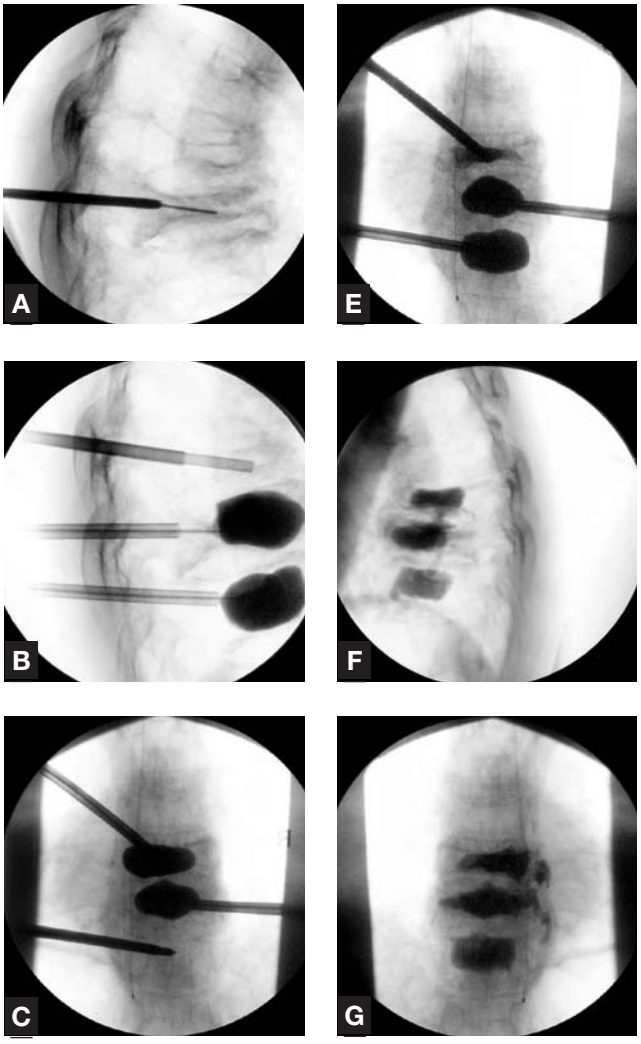

Figure 2. Kyphoplasty: The incision is made 1.5 cm lateral to the pedicle. A Jamshidi needle (11-gauge bone access needle) is located lateral to the lateral wall of the pedicle. The needle is tapped down (not shown). **(A)** The needle is exchanged for a guide wire, followed by an obturator. The obturator is then exchanged for a working cannula. A biopsy is then taken. A wedge instrument is used to open a medial space in the vertebral body (not shown). **(B,C)** The balloon is introduced and inflated correcting the deformity. **(D,E)** The cement is injected. **(F,G)** PA and lateral views showing final result of a 3-level kyphoplasty. Images and caption reproduced from Neviaser A., Toro-Arbelaez J. B., and. Lane J. M. Is Kyphoplasty the Standard of Care for Compression Fractures in the Spine, Especially in the Elderly? *Am J Orthop.* 2005;34(9):425-429. Copyright 2005, Quadrant HealthCom, Inc. Used with permission.

Summary

We have seen many recent advances in spinal surgery technology in which the hope is to offer patients better clinical outcomes with less overall morbidity. Less invasive surgical strategies (eg, IDET, kyphoplasty, vertebroplasty, thoracoscopy) are providing the same clinical results as more invasive open procedures. Improved bone graft substitutes (BMP) and extenders (DBM) are being made commercially available, with an increasing potential for obtaining spinal fusion with less success with less need for autologous bone graft harvest and associated morbidity. In Europe and now in the United States, cervical and lumbar intervertebral disc replacements are showing promise in patient cohort prospective studies. Although these newer technologies look promising in the management of various spinal disorders, careful prospective, long-term trials are needed to fully define their role.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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This paper will be judged for the Resident Writer's Award.