Futuristic Approach to Spinal Surgery

Great advances in just the past decade have allowed physicians to treat spinal disorders more effectively. Further advances in motion preservation techniques, minimally invasive access surgery, computer-assisted image-guided (spinal navigation) technology, biomaterial development, molecular biology of bone and disc will all be integrated together to develop very powerful techniques for treating spinal disorders.

Motion Preservation

There are a wide variety of posterior motion preservation devices in various stages of development and clinical investigation. The intent of these devices is to provide a better treatment alternative than spine fusion for patients with pain and loss of function caused by specific back problems, such as lumbar spinal stenosis, facet pain, and degenerative disc disease.

For patients with ongoing pain originating from the spine, the classic surgical treatment has usually been spinal fusion. Similar to degenerative painful conditions of the hip and knee, degenerative, painful spine surgical treatment is now evolving from fusion, which eliminates motion at the joint, to the goal of *motion preservation*. There are several alternative approaches to motion preservation, some of which have been approved for use in the general patient population in the US and many of which are in various stages of development and clinical trials:

- **Total disc replacement.** The initial approach for motion preservation has involved total disc replacement to address painful disc degeneration. However there is an ongoing process of development of this technology and long terms results are still to be ascertained.
- **Disc nucleus replacement.** Also in development are nucleus replacement devices, which seek to address discogenic pain by replacing only the disc nucleus (the center of the disc) while leaving the outer portion (the annulus) of the disc intact.

- **Interspinous process spacers**. These devices are designed to distract (open) the central canal and foramen, where the nerve endings pass away from the center of the spinal region and into the legs. These devices are designed to address pain and activity restrictions from spinal stenosis, and some may be used to treat degenerative disc disease.

- **Posterior dynamic stabilization devices**. Analogous to an internal brace on the spine, the goal of posterior dynamic stabilization devices is to allow controlled motion in such as way as to achieve more normal movement of the spine. Clinical trials are currently underway for some of these devices for use as stand-alone devices (without fusion), and for use in the treatment of lumbar spinal stenosis.
- **Facet replacement or total element replacement devices** for spinal stenosis. These devices are primarily designed to address pain due to facet pain or lumbar

spinal stenosis (narrowing of the passageways of the nerves). For many patients, spinal stenosis is due to degeneration of the facet joints.

Minimal Access Surgery

Minimal access surgery is completed with one or more small incisions instead of a large incision. The surgeon passes a telescope with video camera through a small incision (usually only ¼" long) into a body cavity or attaches a camera to a tubular retractor which is put in after dilatation of the muscles. The surgeon then views the surgery on a TV monitor. Surgical instruments are then passed through the same or other similar little incisions. The surgeon examines and operates on the area in question by viewing magnified images on a television. When the telescope is used to operate on the abdomen, the procedure is called laparoscopy. When used in the chest, the procedure is called thoracoscopy, and when used in a joint, it is called arthroscopy.

For the spine various minimal access surgery techniques include

- Endoscopic discectomy (various types)
- Video assisted thoracosocopy surgery for
    - Infections (tuberculosis of spine)
    - Trauma
    - Anterior release in scoliosis etc
- Laproscopic fusion surgery

Spinal Navigation Technology

Conventional surgery of the spine often involves taking an x-ray during the procedure to confirm the location of the spine or to confirm satisfactory placement of spinal implants (e.g. screws, rods, hooks, plates). Often, surgeons use fluoroscopy to obtain this information.

In the past decade, great advances have been made that has taken navigation of the spine (or localization) to a new height. Also known as "computer-assisted, image-guidance," navigation technology is advancing at a rapid rate. More powerful and elegant than simple x-ray technology, spinal navigation technology uses a computer and radiographic studies (x-rays) of the patient to allow the surgeon to know precisely where he/she is at all times.

Spinal navigation technology enables the surgeon to more accurately place spinal instrumentation, perform decompression (e.g. eliminate pressure on nerves), remove tumors, and other tasks. Three-dimensional models of a patient's own spine appear on a computer screen with virtual representations of real surgical instruments that the surgeons have in their hand. Surgeries can even be planned 'virtually' on the computer before a patient even goes to sleep under anesthesia. For example, screw diameter, length, and other measurements can be made with greater accuracy.

The future of spinal navigation is exciting. Rather than send a patient for an preoperative CT or MRI scan, in the future surgeons will be able to obtain images in the operating room that can instantly create computer models of the patient's spine. These models can be used to help navigate the spine during surgery. Intraoperative CT, MRI, and fluoroscopy-based CT offer great potential. The end result is enabling the surgeon to visually "travel" in and out of a patient's spine on computer, thereby allowing them to see things that the human eye cannot during a typical surgery. As spinal navigation technology advances, newer minimally invasive techniques will become available.

Robotics in surgery

Robotics is rapidly developing in surgery, although the word is slightly misused in this connection. None of the systems under development involves a machine acting autonomously. Instead, the machine acts as a remote extension of the surgeon. The correct term for such a system is a "master slave manipulator," although it seems unlikely that this term will gain general currency.

Minimal invasive surgery is itself a form of telemanipulation because the surgeon is physically separated from the workspace. Telerobotics is an obvious tool to extend the surgeons' capabilities. The goal is to restore the tactile cues and intuitive dexterity of the surgeon, which are diminished by minimal invasive surgery. A slave manipulator, controlled through a spatially consistent and intuitive master with a force feedback (haptic) system, could replace the tactile sensibilities and restore dexterity.

Several passive mechanical devices, primarily used to hold the telescope, have been developed as assistants for general laparoscopic surgery. They successfully reduce the stress on the surgeon by eliminating the inadvertent movements of a human assistant, which can be distracting and disorienting.

"Motion scaling" software is used to translate large natural movements to extremely precise micromovements. Surgeons can immediately observe the instruments in the patient's body respond to the movements of their hands on the handles, as if they were performing the operation directly. This avoids the need for the reversed counterintuitive motions used in minimally invasive surgery.

Various such systems are in various stages of development. It is estimated that such techniques would have a substantial role to play in spine surgery in the future.

Biomaterial Development

Bone Morphogenetic Proteins (BMP)

Genetically-engineered proteins called Bone Morphogenetic Proteins (BMP) are now commercially available for bone fusion surgery. This will likely eliminate the need for either autologous or allograft bone use and all of the potential morbidity and limitations inherent in these grafts. BMP can be placed inside a collagen (protein) sponge or other ceramic-type implants and used instead of bone in areas of desired fusion (e.g. disc space, backside of the spine). Thus, in the future, we may be using biodegradable spacers or "fusion carriers" that house BMP, allow for a solid fusion, and then dissolve away themselves leaving only fusion bone behind.

Ceramic and Carbon Fiber

Other materials have been used as carriers of bone graft or vertebral body replacements such as ceramic and carbon fiber. Carbon fiber is radiolucent, which means that implants made of this material do not show up on x-ray. This has the advantage of allowing the bone fusion to be better seen. Future developments will bring even greater advances.

Plastics and Polymers

Because of the potential morbidity of using a patient's own bone (autologous bone) and the limited supply of cadaveric bone, attention has been directed to developing newer materials to serve as spacers and conduits for bone graft material. Other forms of plastic are being developed such as polyether ketone combinations that will be radiolucent yet provide strength and support.

Polylactic Acid (PLA) polymers are also being developed that can actually biodegrade over time. In other words, the PLA will do its job in holding bone graft material and providing support long enough for a fusion to take place, and then it slowly dissolves (hydrolyzes) away after a year or so. Still other materials are being developed that would allow some flexibility and dynamism in a spinal implant. There is some agreement that certain spinal implants may be too rigid and more natural, flexible substances may be a better substrate from which implants could be made.

Biologic Treatments for Disc Degeneration

Disc degeneration remains an endemic reality of aging. As is the case with most conditions, there is likely to be some genetic predisposition. At the present time, the biologic treatment of disc degeneration remains solely in the realm of research. Progress continues slowly to surpass a variety of obstacles.First, the development and validation of animal models of disc degeneration continue to be a major limitation. The vast majority of models are disc injury models, which may or may not be relevant to natural disc aging. Studies continue to examine the effect of techanical forces on normal disc nutrition and health. A third area that requires advances is the quantitative noninvasive detection and monitoring of disc degeneration. More sophisticated use of magnetic resonance imaging may serve this role in the future. One possible approach to the treatment of disc degeneration that is confined to the nucleus pulposus would be to revitalize the tissue by implanting or injecting cells that have the potential to restore functionality. These cells could be bone marrow mesenchymal cells or culture-expanded disc cartilage cells. A recent study of rabbit intervertebral discs demonstrated that bone mesenchymal stem cells could be transplanted and could survive to increase proteoglycan synthesis. Another group of investigators tested cell viability when cells were delivered with a fibrin gel into rabbit intervertebral discs, highlighting just one of the challenges of intradiscal cell therapy. If disc degeneration occurs because of, or results in, nutritional compromise, then the survivability of transplanted cells would be in question. Work continues in this area, although the challenges remain quite substantial.

Cell-based therapies for use in spinal procedures are clearly in their infancy; however, numerous preclinical studies in a variety of animal models support the belief that mesenchymal stem cells have a bright future, especially in the area of disc repair and spinal fusions. In addition, stem cells that have been differentiated into a neural phenotype may also be used for repair and regeneration of the spinal cord, although this is a much more difficult application than musculoskeletal tissue repair. Cell viability and cellular rejection remain significant hurdles before these techniques will be successful in the human population, although it can be predicted that cell-based therapies are clearly in the future of spine surgery.