ABSTRACT
The article reviews milestones in spine care that have occurred in the past 100 years. The various conditions and diagnoses we commonly treat today were poorly understood and there were few reliable treatments available in the first half of the twentieth century. Various diagnostic and imaging techniques have evolved as well as nonoperative and operative modalities to treat deformity, degenerative, and traumatic spine conditions. The reader should gain an understanding and appreciation of how interrelated the early concepts of management and treatment relate to the procedures and technology we take for granted today.

Keywords: Historical Milestones, Spine Care, Spine Surgery.

EARLY FUSION TECHNIQUES
Most sufferers of spine conditions and neural pain were relegated to periods of prolonged bed rest, traction, and bracing since surgical care was not embraced as an effective or safe option. The surgical procedures pioneered in the early 1900s were for treatment of spinal deformity due to tuberculosis (Potts' disease).

Albee described the H graft onlay fusion across the lumbosacral joint. During the same year, Hibbs described his gouge and curl technique of posterior spinal fusion. Hibbs augmented local bone with autologous iliac bone to further promote fusion.

Dandy at John Hopkins described nodules of discal origin that he thought to be tumors which caused compression on spinal nerves resulting in sciatica. Mixter and Barr were the first to recognize that these “tumors” called chondromas were actually herniated intervertebral discs.

King used facet screws to fix lumbosacral joint fusions. Baker and Hoyt at Duke reported on the Hibbs’ technique for spinal fusion and added interfacet screws for stabilization in 1948. Boucher inserted facet–vertebral body screws to stabilize posterior fusions. Pennal et al in 1964 used an obliquely directed facet–pedicle screw ending in the vertebral body. Both the Boucher and Pennal screws traversed the same path of insertion of the pedicle screws used today (Fig. 1).

SCOLIOSIS TREATMENT
Most patients with adolescent idiopathic scoliosis were treated with bracing, traction, and casting. Blount et al along with orthotist Schmidt developed the Milwaukee brace for the ambulatory treatment of scoliosis. Later, Hall et al popularized the underarm thoracolumbar sacral...
orthosis which was less visible than the Milwaukee brace. Cotrel\textsuperscript{11} applied dynamic traction to the pelvis and head/neck (cephalopelvic) to correct moderately severe curves for a period of time before corrective surgery. Turnbuckle and Risser casting were used to correct scoliosis prior to operative intervention without instrumentation and to maintain and improve correction following posterior fusion\textsuperscript{12} (Fig. 2). Patients were often operated in their casts and kept in casts at bed rest for 6 to 9 months following surgery. Halo wheelchair and Halo-Pelvic traction are still used today.\textsuperscript{13,14}

In the 1960s, Harrington\textsuperscript{15} instrumentation was coupled with the Hibbs–Moe fusion for paralytic and idiopathic scoliosis (Figs 3 and 4). This was a major breakthrough in spinal corrective surgery although not embraced by many who considered the procedure of distraction too risky in the adolescent spine. Many of Harrington’s polio cases instrumented without spinal fusion failed. The addition of the Hibbs–Moe fusion resulted in better outcomes.\textsuperscript{16,17} Ambulation in a cast following surgery was popularized by Winter of Minneapolis.\textsuperscript{18}

Dwyer\textsuperscript{19} used a cable and vertebral screw system for anterior correction of scoliosis, which required an extensive thoracoabdominal approach with take-down of the diaphragm. Because of the flexible cable, failure of the device was not uncommon. Hall\textsuperscript{20} modified the Dwyer system by using a solid rod rather than a flexible cable. Zielke rods were effective in correcting thoracolumbar scoliotic curves with anterior placed interbody grafts and derotation.\textsuperscript{21}

Luque\textsuperscript{22} introduced segmental spinal instrumentation (SSI) using dual rods which were bent to retain kyphosis and lordosis secured with sublaminar wires and iliac fixation to the paralytic spine. Segmental spinal
instrumentation was also used to treat adolescent idiopathic curves (Fig. 5). Cotrel et al \(^2^3\) introduced a multiple hook and dual rod system to treat scoliosis in the mid-1980s which provided derotation as well as distraction corrective forces. Suk et al \(^2^4,2^5\) in the mid-1990s described the use of pedicle screw instrumentation to correct adolescent idiopathic scoliosis. Transition to pedicle screw-based constructs completely changed the surgical treatment of both adolescent and adult scoliosis.

**IMAGING AND OTHER DIAGNOSTIC TECHNIQUES**

In 1921, Lipiodol \(^{2^6}\) (Guerbet, France), a poppy seed oil, was used to visualize the spinal canal through a subarachnoid injection. Later, Pantopaque \(^{2^7}\) (Eastman Kodak), another organic oil-based dye, was used in myelography. Both of these radiographic agents required removal which was often difficult. These dyes also caused arachnoiditis. Metrizamide, a water-soluble nonionic contrast agent, was introduced in the mid-1970s. \(^{2^8}\) This agent did not require removal and was compatible with computerized tomography (CT). Computerized tomographic myelography became the gold standard for diagnosis in spine pathology until the advent of magnetic resonance imaging (MRI). \(^{2^9}\)

Discography was popularized in the 1960s as a method for evaluating intervertebral disk integrity. \(^{3^1}\) Following discography, CT scanning was done. Leakage of dye injected into the center of the disk through annular fissures and recreation of the patient’s pain was considered diagnostic of discogenic pain. Pressurizing the disk with contrast or saline was done to reproduce pain similar to what the patient was experiencing. \(^{3^2}\)

Needle electromyography and nerve conduction studies are valuable in verifying the nerve roots involved in patients with radicular pain and compressive nerve syndromes and excluding primary muscle and demyelinating diseases. \(^{3^3}\)

Although epidural lumbar steroid injections have been used for treatment of lumbar radicular pain, they have no localizing value. \(^{3^4}\) Selective nerve root blocks have proven of value in correlating the patients’ radicular pain with the involved nerve root(s). \(^{3^5}\) Facet blocks are useful in the evaluation of mechanical low back pain. \(^{3^6}\)

**NONOPERATIVE MODALITIES**

Chymopapain \(^{3^7}\) (Smith laboratories, Libertyville, Il) injected into the disk of a patient with a herniated disk was successful in a number of patients but was complicated by paraplegia and anaphylactic shock in a small number. It was discontinued shortly after its introduction in the early 1970s. \(^{3^8}\) Intradiscal steroids were also used in patients with lumbar herniated discs and discogenic pain. \(^{3^9}\)

Gravity reduction lumbar therapy was introduced at the Sister Kenny Institute in Minneapolis in the 1970s and is still used today to unweight the painful spine. \(^{4^0}\) McKenzie \(^{4^1}\) Extension exercises have gained popularity in the rehabilitation of patients with lumbar and radicular pain complaints. Bracing and prolonged bed rest have been replaced by more hands-on physical therapy and active core exercise programs to improve muscle strength and balance.

**PEDICLE SCREWS**

Roy-Camille et al, \(^{4^2}\) Dick, \(^{4^3}\) Magerl, \(^{4^4}\) and others used screws placed in the pedicles to treat spine fractures in Europe in the 1970s. Pedicle screws were introduced in the United States by Arthur Steffe and others in the early 1980s. \(^{4^5}\) They were initially used with plates which...
limited the application of corrective forces. Contoured dual rod systems made application easier and correction in three dimensions possible.

The invasive nature and possibility of neural damage during insertion of pedicle screws were of great concern to many spine surgeons and to the Food and Drug Administration (FDA). Reports of complications and poor outcomes surfaced. Pedicle screw litigation against the North American Spine Society, Scoliosis Research Society, American Academy of Orthopaedic Surgeons, American Association of Neurological Surgeons, and several spine surgeons were filed by a group of Philadelphia Plaintiffs’ attorneys in 1994. After a number of depositions and at great expense to the societies involved, the pedicle screw litigation was overturned in 1999. Pedicle screws were not approved for use by the FDA until 1999 following the dismissal of the pedicle screw litigation.

INTERVERTEBRAL BONE GRAFTS AND CAGES

Many surgeons during the 1960 and 1970s used various types of bone grafts to augment fusion between vertebrae in the lumbar spine. Anterior cervical fusion using autogenous iliac grafts and allograft bone produced good to excellent results. However, autografts and allografts placed in the lumbar spine did not result in good outcomes due to the loss of structural integrity during the long healing process, which resulted in instability and high rates of nonunion (Fig. 6). To counteract this, Kuslich et al., Brantigan et al., and Ray used metallic cages in the 1990s to house and support the bone grafts during healing (Fig. 7). It was found necessary to support and lock in both anterior and posterior placed cages with pedicle screw instrumentation to prevent subsidence and migration of the implants.

OPERATIVE APPROACHES TO THE CERVICAL, THORACIC, AND LUMBAR SPINE

Smith and Robinson, Cloward, and Bailey and Badgley popularized the anterior approach to the cervical spine for discectomy and fusion using various types and sources of bone grafts. Laminoplasty for cervical spondylosis with nerve root and cord compression became a popular alternative to extensive laminectomies that occasionally resulted in progressive cervical kyphosis. Lamino-foraminotomy done through a small incision yielded good results in treating patients with cervical root compression due to foraminal stenosis and degenerative facet disease. Hodgson and Stock came to Duke in 1968 and performed three anterior approaches to the thoracic spine for decompression of the spinal cord and stabilization. This operation was referred to as the Hong Kong operation for Potts’ disease. It provided direct exposure of the vertebral body(s) and disc(s) in contrast to the indirect exposure afforded by the costotransversectomy approach. This approach opened up a new portal for treating thoracic spine fractures, tumors, and deformities. Lane and Moore, Harmon, Goldner et al., and others reported in the 1960s and 1970s on their experiences with the transperitoneal and later the retroperitoneal approach to the lumbar spine to treat disorders, such as disk resorption, degenerative disk disease, pyogenic discitis, and failed posterior discectomies and laminectomies. Posterior lumbar interbody fusion required a generous laminectomy and facetectomy to make room for placement of instrumentation and grafts without injury to the dural contents and adjacent nerve roots. Harms and Jeszensky developed the transforaminal lumbar interbody fusion technique utilizing facetectomy, distraction using pedicle screws to widen the disk space, and interbody fusion with titanium cages and autogenous bone.
The lateral approach to the thoracolumbar spine with take-down of the diaphragm had been done for many years to correct scoliotic curves. In the mid-1990s, the extreme lateral interbody fusion technique (XLIF) was popularized by Ozgur et al. They approached the lateral spine through a mid-auxiliary incision entering the retroperitoneal space. Using a neural probe to monitor and guide them away from the branches of the lumbosacral plexus, they penetrated the psoas muscle to reach the desired disk space. Some patients experienced various degrees of radicular pain following XLIF due to traction on the lumbosacral nerve roots from the expandable tubular retractor. The lateral interbody approach was modified to reduce the neural complications but entering anterior to the psoas muscle. Polyether ether ketone cages and pedicle screw fixation resulted in correction and stabilization of degenerative lumbar curves (Fig. 8).

The paracoccygeal transsacral approach through the avascular space anterior to the sacrum provided direct access for interbody fusion of L5-S1 and L4-L5. It was first described by Cragg et al. in 2004. Advantages of this approach include lack of damage to muscular, neural, ligamentous, and vascular structures. Early complications of rectal tears were subsequently reduced with protective devices and improved instrumentation.

TREATMENT OF SPINAL INJURIES

Spine fractures and dislocations were treated with bed rest on turning frames, manipulation, and casting. Cervical traction applied to the skull was used to reduce dislocations, after which the patient was placed in a Minerva cast or Four Poster cervical brace. The Halo ring attached to a body cast or brace made the care of these injuries much more predictable and easier on the patient (Fig. 9).

OSTEOTOMIES TO CORRECT SPINAL DEFORMITY

Smith Peterson et al. described a wide lumbar laminectomy, and facetectomy coupled with a manual extension fracture through disk endplate to regain lumbar lordosis in patients with ankylosing spondylitis.

Heinig performed a laminectomy followed by an “Eggshell” procedure through the pedicles by removing
a wedge of posterior vertebral bone and tamping down
the posterior vertebral wall to regain extension of the
lumbar spine.

Ponte did facetectomies at several levels to treat
Scheuermann’s kyphosis using segmental posterior
shortening and pedicle instrumentation.67

Three-column pedicle subtraction osteotomy is an
effective way to correct flat back deformity as is vertebral
column resection for kyphoscoliosis.68,69

Simmons70 posterior cervical osteotomy coupled with
gradual extension in the awake patient was successful
in treating chin on chest deformity in patients with
ankylosing spondylitis.

CERVICAL/LUMBAR ARTHROPLASTY

The Bryan metal on polymer prosthesis was the first
approved device for cervical disk arthroplasty.71 Designs
currently in use are Pro Disc-C, Mobi-C, and Prestige. These
devices are implanted via a Smith Robinson
cervical approach. Studies have shown that most patients
retain 4° or more in flexion/extension at the operative
level after cervical disk replacement. Coric et al72 found no
significant differences between cervical disk arthroplasty
and anterior cervical discectomy and fusion groups when
comparing operative time, blood loss, length of hospital
stay, or the reoperation rate.

The Charité’ total lumbar disk replacement was FDA
approved in 2004 for use in treating single-level lumbar
disk disease. Due to mechanical problems, it was taken
off the market in 2011. The Pro Disk implant is currently
being used to treat one- and two-level lumbar disk
disease in an attempt to retain motion and reduce the
incidence of adjacent segment breakdown following
lumbar fusion.73

INTRAOPERATIVE MONITORING AND IMAGING

Spinal sensory evoked potential has been used to monitor
spinal cord function during spine operations since the
early 1980s.74 Later, motor evoked potential monitoring
was added.75 Both have been invaluable in alerting the
surgical team of impending spinal cord injury before it
becomes irreversible.76 The C-arm, portable CT scanners,
Operating room-based MRI scanners, spinal navigation,
and robotics are providing the surgeon with much
needed intraoperative imaging and safety when doing
corrective osteotomies and placing instrumentation in
close proximity to neural and vascular structures.

The Cell Saver device recycles, filters, and cleans lost
blood, allowing it to be transfused back into the patient. The
Jackson table allows for safe positioning of the patient in
the prone position while maintaining lordosis and relieving
pressure on the abdominal contents and vena cava.

VERTEBROPLASTY AND KYPHOPLASTY

Stabilization of spinal compression fractures in the thoraco-
lumbar spine with polymethylmethacrylate (PMMA)
have been done for the past 15 years.77 Vertebroplasty is
performed by injecting PMMA through the pedicles of
the fractured vertebra. Kyphoplasty utilizes a balloon
to elevate the compressed bone followed by insertion of
PMMA.78 With both techniques, there can be leakage of
the PMMA into the epidural space. Both procedures must
be done while the fracture fragments are mobile. Recently
an expandable cage has been used to elevate the fracture,
stabilize the reduction, and contain the injected PMMA.

BIOCERAMICS AND RH BMP-2

Hydroxyapatite and calcium triphosphate have been
used with dental and orthopaedic bone grafts for the past
40 years.79 These bioceermics are added to demineralized
bone, allografts, and autografts to augment spinal
fusions80 (Fig. 10). Recently, these agents have been
combined with stem cells and bone marrow aspirates.81
Bone morphogenic protein, rhBMP-2, was FDA approved
for anterior lumbar interbody fusions in 2002. Because
of cost and reimbursement issues, its use has been less
popular. Some studies have shown rhBMP-2 to be no
more effective than autogenous bone and bioceermics
in promoting spinal fusions.82,83

FUTURE CHALLENGES

Reducing morbidity and complications in treating older
patients with spine deformities is paramount. Minimally
invasive techniques show promise in reducing blood
loss, hospital stay, and faster return to activities of daily
living. The use of expandable cages with variable angles

Fig. 10: Hematoxylin and eosin stain of posterior fusion uti-
zizing allograft bone mixed with hydroxyapatite and calcium
triphosphate
may allow for correction of lumbar kyphosis and flat back without the need to perform pedicle subtraction and other types of osteotomies. Insertion of pedicle screws and spinal instrumentation using percutaneous and minimally invasive techniques has proven to be safe and efficient (Figs 11 and 12).

Prevention and treatment of early-onset degenerative disk disease with intradiscal biologicals and supplements may reverse the degenerative cascade of spinal arthritis, which is a major source of disability in the modern world.

Motion preservation rather than fusion of lumbar spine segments in younger patients using expandable implants may be possible with newer materials and surgical approaches.

Although early operative intervention in treating spinal fractures and dislocations has resulted in less downtime and complications, reversal of spinal cord and neural injury is still a major challenge.

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