

Instrumentation in Spinal Surgery

H K Wong,**FAMS, FRCS (Glas), MCh (Orth)*, H T Hee,***FAMS, FRCS (Edin), FRCS (Glas)*

Abstract

As a result of rapid advances in the field of spinal instrumentation, the surgeon today has at his disposal many well-designed implants, such as pedicle screws, hooks, rods, plates, and interbody fusion devices. Many of these implants are modular and are used in combination, such as hooks and screws attached to rods, allowing the surgeon flexibility in selecting the appropriate implants to meet the particular needs of the patient. Spinal instrumentation restores or enhances the mechanical stability of the spine, corrects and maintains spinal alignment, and enhances spinal fusion. The disadvantages associated with the use of instrumentation include increases in cost, operative time, infection rate, re-operation rate, and a steep learning curve. As spinal instrumentation is evolving constantly, it is important to understand the surgical indications and principles of its use. Being highly trained and familiar with the use of these implants is the only sure way to avoid the potentially serious complications that have been associated with their use.

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Introduction

Spinal instrumentation is defined as the use of mechanical devices that enhance or restore the segmental stability of the spine. Internal fixation of the spine began more than a hundred years ago and initially consisted of wires, and/or rods attached to the spine. William F Wilkins was reportedly the first to perform metallic internal fixation of the spine in 1888.¹ He operated on a 6-day-old child with a fracture/dislocation of T12 on L1. Fusion of the spine was first described by Hibbs (1911) and Albee (1911) in the beginning of the 20th century.¹ Facet arthrodesis with screws was first performed in 1944 by King.¹ The rod-hook system of Harrington,² originally developed in the 1950s for the treatment of the paralytic spine, was a major contribution in the surgical treatment of scoliosis, and remained in use till the mid 80s when the CD (Cotrel and Dubousset) instrumentation made its first appearance.

It was only in the last 2 decades that a tremendous growth of spinal instrumentation was seen. This was due to better understanding of the biomechanics of the spine, pathophysiology of various spinal disorders, as well as improved design and manufacturing of the implants. The introduction of better surgical techniques also made these

advances possible. Equally important, especially in the correction of spinal deformity and placement of pedicle screws into the thoracic spine, was the development of spinal cord monitoring. Spinal cord monitoring began in France with the wake-up test (Vauzelle et al 1973) and this then evolved into somatosensory evoked potential (SSEP) monitoring (Nash et al 1974).¹ This undoubtedly increases safety to patients when instrumentation of the spine is performed.

Although the Harrington system was a big step forward, it did have several disadvantages in that fixation depended on the security of the hooks at each end of the rod. At that time, a number of surgeons recognised that the spine is a segmental structure and that effective fixation should also be segmental. The concept of multi-segmental spinal fixation began in the 1970s, pioneered by Luque and Roy-Camille.¹ Segmental sublaminae wiring of the spine was popularised by Luque in 1974. Thereafter, this concept was further modified by Dove (1987) by combining the 2 Luque rods into a single construct, also known as the Hartshill rectangle. Roy-Camille's concept of segmental fixation was that of pedicle screws connected by a plate. The concept was taken further by Dywer to include

* Associate Professor

** Assistant Professor and Consultant

Division of Spinal Surgery

Department of Orthopaedic Surgery

National University Hospital

Address for Reprints: A/P Wong Hee Kit, Division of Spinal Surgery, Department of Orthopaedic Surgery, National University Hospital, 5 Lower Kent Ridge Road, Singapore 119074. E-mail: doswhk@nus.edu.sg

segmental anterior spinal fixation. The most recent development of segmental fixation came from Cotrel and Dubousset in France,³ and consisted of double rods connected via hooks and pedicle screws. The development of segmental fixation systems not only allowed more secure fixation and better correction of spinal deformity, but also enabled the surgeon to reproduce the normal sagittal alignment of the spine.

White and Panjabi⁴ contributed greatly to our understanding of the biomechanics of the spine. The anterior column (ventral to the neural elements) absorbs 80% of the axial load as compressive force. The remaining 20% is shared within the posterior column as shear force.⁵ The importance of restoring the anterior column in cases with defects of the anterior column led to the development and utilisation of anterior support systems (e.g. cages) that may be “stand-alone” or may be used with supplemental posterior stabilisation. In doing so, we are able to restore the capability of the anterior column to resist compressive forces. The anterior devices (e.g. cages) are inserted with a distraction manoeuvre. The anterior devices must not only be able to resist compression or axial loading, they must also have torsional resistance. Some of these anterior devices may be inserted using endoscopic techniques, with reduced patient morbidity. The use of minimally invasive spine surgery is gradually being viewed by the spine and orthopaedic community as a valuable tool in the management of spinal pathologies. Examples include thoracoscopic release and instrumentation in the treatment of scoliosis, percutaneous vertebroplasty or kyphoplasty in treating osteoporotic compression fractures, endoscopic discectomy for managing prolapsed discs, and intradiscal electrothermal annuloplasty (IDET) for treating discogenic back pain.

Although in their infancy, computer-aided surgical navigation systems are improving at a very fast pace. It is now possible to place pedicle screws in the thoracic and lumbar spine using small stab incisions. Before long, the spine surgeon may have at his disposal minimally invasive instrumentation systems for use throughout the spine.

Despite these advances, clinical success is far from certain. A 100% fusion rate is not yet attainable, despite the use of spinal instrumentation, bone graft substitutes, and osteoinductive substances. A good fusion also does not guarantee a good clinical outcome. In the end, patient selection remains the only reliable aspect for the successful use of various spinal instrumentation systems.

The Use of Spinal Instrumentation in Deformity

The surgical treatment of scoliosis has evolved over the past 70 years from posterior fusion and cast correction techniques to a variety of anterior and posterior techniques using an even greater variety of instrumentation systems.

Harrington instrumentation, introduced in the 1950s and which gained popularity in the 1960s, represented the first effective instrumentation for the correction of scoliosis.² Its concept is based on the application of a distractive force across two points, one at each end of the concave side of the spinal curvature to effect straightening and stabilisation of the spine. Compression using hooks applied to the convex side of the spine was added to the instrumentation in subsequent years. This technique allowed early ambulation of the patient in a cast and at the same time decreased pseudarthrosis rates by 50% compared to fusion and casting alone.⁶ Although it was simple, safe and inexpensive, Harrington instrumentation was disadvantaged by poor sagittal plane control, particularly when it had to span the lumbar spine, where distraction can produce the “flat back” syndrome. It was also difficult to treat double curves with this instrumentation, requiring the rod to cross the spine in the transitional zone in a “dollar-sign” configuration. Such a construct is biomechanically inefficient as well as inelegant. In the 1970s, Luque⁷ introduced the concept of multi-segmental fixation of the spine with sublaminar wires. Transverse traction forces are applied to the spine when tightening the wires, pulling the spine onto the pre-contoured rods. The advantages of Luque instrumentation are better curve correction in both coronal and sagittal profiles, coupled with increased stability as a result of fixation at multiple levels, making postoperative bracing unnecessary. A further refinement of this technique is hybrid Harrington-Luque instrumentation where the concave side Luque rod is replaced by a Harrington rod, adding the advantage of curve distraction. The passage of sublaminar wires, however, was associated with an increased incidence of neurological deficits, a major disadvantage of this system.⁸ As a result, an alternative wiring technique (Wisconsin) was introduced, which involved passing the wires through the base of the spinous process, avoiding intrusion into the spinal canal. Although less efficient in curve correction, Wisconsin wires were safer than sublaminar wires, and hybrid systems, like the Harrington-Luque-Wisconsin instrumentation, remained popular for idiopathic scoliosis in the 1980s before the introduction of the current generation of spinal instrumentation.⁹ Multi-segmental sublaminar wiring on dual Luque rods with one end of each rod contoured and inserted into the iliac bone on either side to control pelvic tilt, viz. the Luque-Galveston technique, remains an excellent instrumentation technique for neuromuscular scoliosis.

The current generation of posterior spinal instrumentation was pioneered by Cotrel and Dubousset in France in 1983 and popularised in the 1990s.¹⁰ Named “CD-I”, this instrumentation system was based on the concept of multiple hook and dual rod fixation to de-rotate the spine. Unlike the

previous multi-segmental wiring systems, the multiple hooks are directional, in that they can be placed facing either cephalad or caudally; and they can also be individually locked onto the rod in their final orientation, giving unprecedented control of the coronal and sagittal planes of the spinal curvature. Because the hooks are situated behind the central axis of the spine, distraction of the concavity of a thoracic curve not only straightens it, but also results in increased kyphosis. Conversely, compression of the convexity of thoracic scoliosis not only results in straightening of the curve, but also reduces the thoracic kyphosis. Thus, in a patient who has thoracic scoliosis with hypokyphosis, which is the most common situation, the concave side rod is implanted and curve distraction is performed first, followed by the convex side rod. The sequence provides curve correction as well as restoration of the normal kyphosis. The sequence of rod implantation is reversed, i.e. convex side rod first; if the patient has thoracic kyphosis, or when correcting lumbar scoliosis, where it is important not to produce kyphosis by distraction. Double curves can also be instrumented with groups of hooks orientated in distraction or compression configuration on the same rod. The result is 3-dimensional control of the spinal curvature in the coronal and sagittal planes, improved correction, and greater stability, obviating the need for postoperative bracing (Fig. 1). Correction of the rotational deformity is, however, less efficient than earlier thought to be. Many surgeons now perform a posterior thoracoplasty through the same posterior midline incision, excising 3 to 4 rib segments in order to reduce the rib hump and at the same time using the ribs as a source of autogenous grafts.

Over the years, a new generation of spinal instrumentation has evolved from the basic CD-I. These, like the CD Horizon, TSRH, Isola, Moss Miami, PASS, Evolution, have unique features such as low implant profile, polyaxial hooks or screws, strong but reversible locking mechanisms, etc., making the instrumentation not only easier to use, but also easier to revise or remove if the need arises. The modularity of today's spinal instrumentation, allowing the use of hooks, wires, and screws on the same construct, is such that any curve type can be adequately treated from the posterior approach. The only disadvantage is the high cost compared to simpler systems.

The use of multi-segmental pedicle screws in posterior spinal instrumentation is a recent development. Its use has generally been limited to the lumbar spine because of safety concerns regarding the placement of screws through the smaller pedicles of the thoracic spine. Experience with lumbar pedicle screw fixation has shown better control of the spinal deformity compared with hooks. Suk et al¹¹ have also reported excellent results with pedicle screws in the thoracic spine. Because pedicle screws control both the anterior and posterior columns of the spine, the corrective

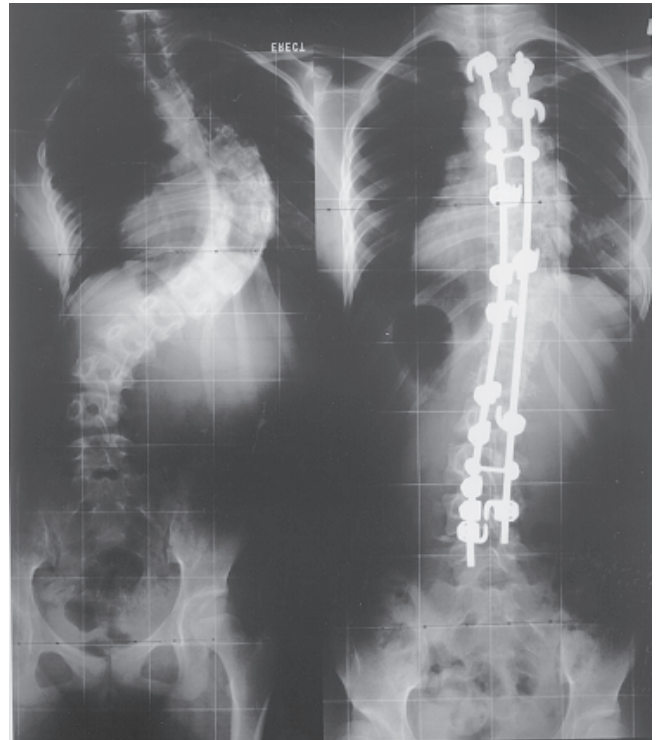


Fig. 1. This 14-year-old with a 95-degree thoracic scoliosis was treated with anterior release through a right thoracotomy, followed by posterior fusion and instrumentation using segmental spinal instrumentation under the same anaesthesia. Thoracoplasty was performed on the right chest wall through the posterior midline incision.

forces largely lie with rod pre-contouring rather than on the distraction and compression strategies as described in the all-hook systems. It is envisaged that pedicle screw fixation for both the thoracic and lumbar spine may form the next standard of posterior spinal instrumentation in scoliosis as surgeons become more familiar with thoracic pedicle screw insertion and with the recent introduction of intraoperative navigation systems to assist in screw placement.

Scoliosis can also be corrected with anterior instrumentation. Anterior surgery may also be used in conjunction with posterior surgery to treat large or rigid curves, or when there is a need to have both anterior and posterior fusion e.g. to prevent crankshaft phenomenon in the very young child.¹² Instrumentation is preceded by multiple level discectomies which reduce the rigidity of the segment and also prepare the interbody spaces for fusion. Dwyer and Schafer¹³ were the first to report the use of anterior spinal instrumentation for thoracolumbar and lumbar scoliosis. In this procedure, screws were placed transversely across the vertebral bodies from the convex side. A flexible cable was used to connect the screw heads, which were then brought together, shortening the convex side of the curve. The cable was subsequently replaced by a threaded rod in the Zielke system. However, as the screws lie anterior to the axis of the vertebral column, compression of the convexity of the curve could at the same time cause

kyphosis of the lumbar spine, a major disadvantage of this technique. The kyphosing effect of anterior instrumentation can be overcome by the placement of structural bone grafts or metallic cage devices in the intervertebral spaces, and by the newer generation anterior spinal instrumentation where solid rods, pre-contoured in lordosis are used in place of the weaker cable or threaded rod systems. More recently, powerful dual rod systems have been developed to correct scoliosis. The anterior screws and rods are very often from the same set of implants used in posterior spinal instrumentation. Solid rod failure rates from pseudarthrosis are lower than those associated with the cable and threaded rod systems. Postoperative bracing is often not necessary with these newer anterior instrumentation systems. Anterior instrumentation has several advantages. It is often possible to instrument one to two levels less than if posterior instrumentation is used, thereby saving mobile segments in the lower lumbar spine. Comparative studies have shown there is greater correction and derotation of the spine using anterior instrumentation.¹⁴ However, with the advent of multi-level pedicle screw fixation from the posterior approach, it remains to be seen if these advantages still hold.

Anterior spinal instrumentation has for many years been applied only to the thoracolumbar and lumbar spine. However, with the development of better and more reliable implants, surgeons have started to use anterior spinal instrumentation for thoracic scoliosis.^{15,16} The procedure is performed through a conventional anterior approach using double thoracotomy, facilitated by ipsilateral deflation of the lung. With the evolution of video-assisted thoracoscopic techniques, it is now possible to correct thoracic scoliosis using specially developed anterior instrumentation through small incisions through the lateral chest wall (Fig. 2). Early experience with this technique has shown it to be safe, and curve corrections are comparable with posterior approaches.^{17,18} The advantages of thoracoscopic instrumentation are possibly less pain, faster recovery, and improved muscle function from avoidance of thoracotomy or posterior paraspinal dissection. This technique holds promise in achieving a better cosmetic outcome for the patient with thoracic scoliosis, but it would be some time yet before its role in scoliosis treatment could be fully defined.

Use of Spinal Instrumentation in Degenerative Conditions

Spinal instrumentation is used in degenerative conditions when there is a need to stabilise the spine, correct deformity, and to enhance fusion. The indications for internal fixation are degenerative spondylolisthesis, iatrogenic instability after wide laminectomy or facetectomy for spinal stenosis, degenerative lumbar scoliosis, failed lumbar surgery, multi-

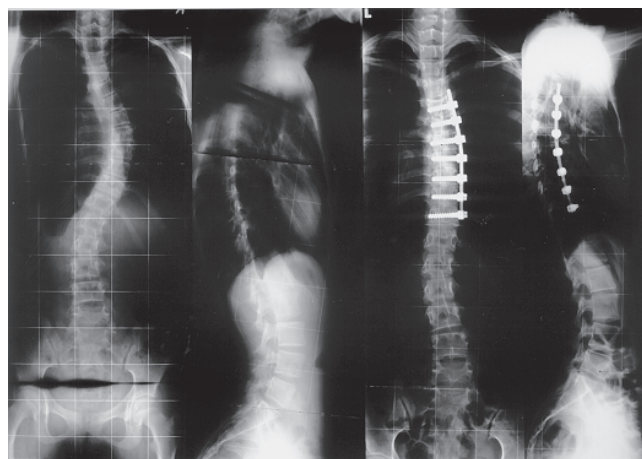


Fig. 2. Anterior fusion and instrumentation was performed thoracoscopically in this patient. Four portals through the right chest wall were used. Bone grafts were taken from the ribs at the access ports.

level fusions, and discogenic pain in degenerative disc disease. Early attempts at spinal instrumentation are posterior distraction systems like Harrington rods or Knodt rods. However, these have little stabilising effect and are inherently kyphogenic, causing loss of the normal lumbar lordosis. In addition, these hook-rod systems cannot be used in after laminectomy, which is a significant disadvantage, as most degenerative conditions that need stabilisation require laminectomy. This has led some surgeons to place the hooks onto an adjacent normal lamina, an unphysiological and undesirable situation. With the introduction of Luque sublaminar wiring in scoliosis in the 1970s, the use of sublaminar wiring and rectangular frames like the Luque rectangle and Hartshill instrumentation became popular for lumbar degenerative disease. However, similar to systems using hooks, sublaminar wiring cannot be used after laminectomy. Furthermore, the inherently poor biomechanical stability of wires on rods often result in loss of fixation and pseudarthrosis.¹⁹

The pedicle screw has been the most significant development of spinal instrumentation.^{20,21} The screw is inserted posteriorly through the pedicle into the vertebral body. By controlling both the anterior and posterior columns of the spine at once, it can resist loads in all planes and can also provide a fulcrum for the correction of rotational and sagittal deformities of the vertebrae instrumented. Lumbar lordosis can be restored, scoliosis can be corrected, and spondylolisthesis stabilised or even reduced. Its use is not dependent on preservation of the posterior elements and thus can be used after laminectomy. Short segment fixation is facilitated. Pedicle screw systems also allow better fixation across the lumbosacral junction compared to previous hook and wiring systems.

Another significant development in spinal instrumentation

in recent years is the introduction of interbody cage devices. These devices replace traditional block bone grafts in the intervertebral space in lumbar interbody fusion. Packed with bone grafts they have a dual function of providing structural support and containment of osteogenic material for fusion. A wide variety of cages have been introduced, viz. threaded cages orientated horizontally; cages placed vertically; trapezoidal shaped cages to restore lumbar lordosis, and innovative designs that allow distraction of the intervertebral space after insertion. Threaded cages like the BAK and TFC are designed for stand-alone use. They restore and maintain segmental stability by distraction of the annulus of the disc, and they can be inserted either from the posterior or anterior approach. Most interbody cages, including vertically-orientated mesh cages like the Harms or Pyramesh cages, are designed for load sharing between the anterior and posterior columns, require supplementary posterior fixation for stability. Instead of bone grafts, bone inductive proteins like BMPs can be packed into these cage devices, saving the need to take autogenous bone grafts. BMP loaded cages are now under investigation to determine their safety and efficacy.

Degenerative Spondylolisthesis

This condition is caused by chronic intervertebral disc and facet joint degeneration. The most commonly affected level is at L4/5, followed by L3/4 and L5/S1. Degenerative spondylolisthesis rarely progresses beyond 25% of the anterior-posterior diameter of the vertebral body. The clinical presentation is usually that of low back pain and radiculopathy. Spinal fusion and decompression have been shown to give better outcome than decompression alone. Deguchi et al²² reported significantly more good to excellent results in the group with rigid instrumentation compared to the non-instrumented group. Similarly, others have reported more rapid fusion, higher fusion rates, better outcome in terms of pain, function and neurological outcome, and less slippage of the spondylolisthesis in those instrumented.²³ Prospective randomised studies have confirmed higher fusion rates, although the functional outcome was found to be no different between instrumented and non-instrumented patients.^{24,25} The disadvantages of instrumentation are increased operative time, blood loss, re-operation rate, and a significant risk of nerve injury.²⁵ The fact that fusion rates do not necessarily predict outcome show how important it is to determine as accurately as possible the site of back pain and radiculopathy in order to achieve a high rate of success. Facet joint injection, provocative discography, or selective nerve root block could be performed for pain localisation, particularly in patients with multi-level degenerative disease. Where the problem is central spinal canal stenosis due to facet enlargement and encroachment, decompression, posterolateral fusion and pedicle screw

fixation is adequate. In patients where there is segmental hypermobility from failure of the intervertebral disc, the addition of anterior column support using either a block bone graft or interbody cage device is advantageous. This can be achieved through a posterior lumbar interbody fusion (PLIF) procedure. Subtotal disc excision is performed from the posterior approach, the vertebral end-plates are decorticated, and block bone grafts or cage devices are placed in the interbody space. Alternatively, a unilateral transforaminal approach (TLIF – transforaminal lumbar interbody fusion) for lumbar interbody fusion could be performed. In this procedure, unilateral facetectomy is performed on the side of radicular symptoms, and through this defect, the intervertebral disc is removed. The interbody cage device or devices packed with bone is then inserted and the procedure is completed by posterior pedicle screw fixation (Fig. 3). The TLIF procedure effectively decompresses both the traversing and exiting nerve roots underneath the facet joint, and is indicated in patients with spondylolisthesis presenting with unilateral radiculopathy. Transforaminal lumbar interbody fusion is the preferred technique over anterior/posterior fusion because it is associated with shorter operating time, less blood loss, shorter hospital stay, and lower incidence of complications.²⁶

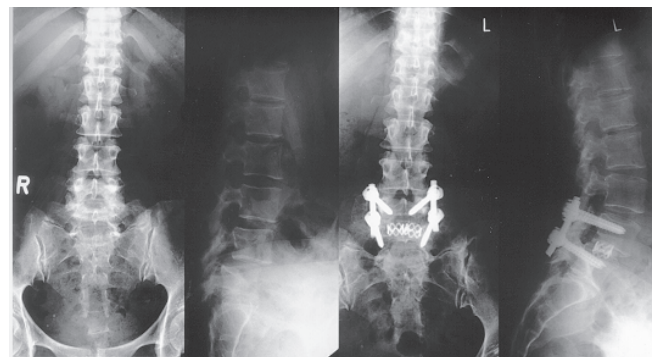


Fig. 3. Transforaminal lumbar interbody fusion (TLIF) for degenerative spondylolisthesis L4L5. The intervertebral disc was approached through a facetectomy on the left side. Bone grafts were placed anterior to the pair of titanium mesh cages and within the cages. Inter-transverse fusion was also performed in this patient.

Iatrogenic Instability

Segmental instability could result after spinal decompressive surgery due to resection of the facet joints, fracture of the pars interarticularis or radical discectomy. Biomechanical analyses have shown that removal of greater than 50% resection of each facet joint at the same level leads to unacceptable segmental instability.²⁷ Iatrogenic instability from extensive facet excision associated with the PLIF procedure will be discussed in the section on degenerative disc disease below. The pars interarticularis

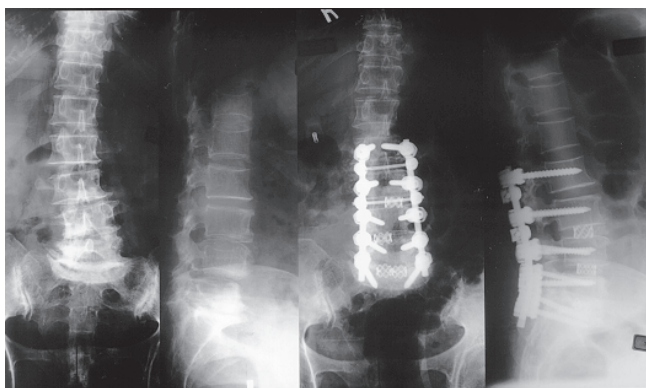


Fig. 4. This elderly patient with degenerative lumbar scoliosis presented with severe back pain and claudicating pain in both lower limbs, worse on the right. The surgical approach was multi-level decompression, unilateral facetectomies and foraminotomies, restoration of both coronal and sagittal alignment by means of interbody mesh cages and pedicle screw fixation.

can be inadvertently fractured during laminectomy and care must be taken to define the lateral edge of the pars and to maintain at least a 5 mm width of this structure. Excessive disc and end-plate removal during discectomy destabilises the anterior column, and spondylolisthesis may occur especially in the presence of laminectomy. Reconstruction of iatrogenic instability is by pedicle screw fixation and posterolateral fusion for posterior deficiencies. Interbody fusion and posterior pedicle screw fixation are indicated for iatrogenic spondylolisthesis or kyphosis.

Degenerative Lumbar Scoliosis

Degenerative scoliosis is due to disc degeneration and facet joint failure. The apex of the curve is usually in the mid-lumbar region, with a short compensatory curve below at L4/5 or L5/S1. Lateral subluxation of the vertebrae may occur. Patients present with back pain, with radicular symptoms due to nerve root compression at the concavities of the curves. Although most patients do not require surgery, surgical treatment may be necessary for persistent and disabling symptoms. Decompression without fusion may lead to further collapse of the curve, instability, and persistence or recurrence of back pain and neurological symptoms. It is nevertheless difficult to predict the progression of the deformity. The extent of fusion and instrumentation remains controversial. Generally, patients with small curves with minimal degenerative changes, and who have clearly defined segmental involvement can be treated by short segment stabilisation after decompression; whilst those with significant multi-level disease and subluxation may be treated by long segment instrumentation with the aim of restoring coronal and sagittal plane balance.²⁸ The upper end of fusion and instrumentation is at a horizontal vertebra adjacent to a normal disc; the lower end is at either L5 or S1. The surgical approach could be from posterior only, or anterior combined with posterior reconstruction.

The posterior only approach involves multiple level foraminotomies in the concavities of the curves, unilateral interbody cage devices, and pedicle screw fixation, similar to the TLIF procedure above, but done at multiple levels (Fig. 4). Decompression of nerve roots in the neuroforamina can be achieved during this procedure. It also avoids an additional anterior stage in these elderly patients, many of whom have concomitant medical illnesses. In the combined approach, the intervertebral discs are removed from the anterior approach, interbody fusion is performed, and the surgery completed from the back by pedicle screw fixation. The advantages of this approach are better restoration of lumbar lordosis, avoidance of canal intrusion and epidural bleeding that are associated with posterior interbody fusion.

Degenerative Disc Disease

The indications for fusion in discogenic pain from degenerative disc disease without radiculopathy are still controversial, and its detailed discussion lies beyond the scope of this article. The underlying premise of surgical treatment is to eliminate the source of pain, i.e. the degenerated disc, by disc excision and fusion. Traditionally, disc excision and fusion is performed either from the posterior approach as in the PLIF procedure, or from the anterior approach as in anterior lumbar interbody fusion (ALIF). Spinal instrumentation is used to enhance fusion by increasing the stability of the reconstructed spinal segment. This is particularly important in PLIF where the spinal segment may be destabilised as a result of the wide laminectomy and facetectomy performed in the surgical approach. Pedicle screw fixation has been shown to increase fusion rates compared to non-instrumented PLIF. The fusion rates from anterior lumbar interbody fusion vary from 35% to 96% and there is no clear consensus as to the necessity for instrumentation.²⁹ The anatomy of the lower lumbar spine does not allow safe anterior instrumentation; and pseudarthrosis from anterior lumbar interbody fusion is best treated by posterior pedicle screw fixation and posterolateral fusion. In recent years, threaded cylindrical interbody cage devices have been introduced for use in lumbar interbody fusion to overcome the problems of bone graft collapse and pseudarthrosis associated with traditional lumbar interbody fusion. Although these cages, when inserted in pairs from the posterior approach in PLIF, have been shown to give good results comparable with 360 degrees fusion,^{30,31} they often require wide posterior exposure, including facetectomy, for their insertion, raising concerns of postoperative spinal instability. In a study on the possibility of cage pairs fitting between the facet joints in an Asian population, Wong et al³² reported that a large proportion of paired cylindrical interbody devices would be too large to fit between the facet joints in the lower lumbar spine in a PLIF procedure, and that cage installation

in the majority of patients is likely to require near total or total facetectomy. Biomechanical studies have shown that after facetectomy, increasing the size of the cages to augment ligamentotaxis does not contribute to increased segmental stiffness.³³ It is recommended that the insertion of cage devices from the posterior approach be supplemented by posterior internal fixation.

Use of Spinal Instrumentation in Trauma

The concept of spinal stability following trauma continues to develop. Holdsworth initially proposed the two-column (anterior and posterior) concept of spinal stability. Destruction of either column will lead to instability. With the use of CT scans in clinical practice, the three-column theory of spinal stability was proposed by Denis.³⁴ Injuries associated with spinal instability include those with involvement of 2 out of 3 columns. Examples of unstable injuries are severe burst fractures with bony retropulsion, flexion-distraction injuries, and fracture-dislocations of the spine. Currently used classification of spinal trauma also includes the AO classification proposed by Magerl, Aebi, and Gertzbein et al.³⁵ Gaines³⁶ also described the load-sharing classification to permit quantification of comminution of spinal fracture sites so that the load-sharing capability of the injured vertebral body itself, along with the implant system, can be determined.

The objective of treatment is to restore the functional anatomy of the spine and to achieve maximum stability immediately, including only the damaged segments in the fusion. The use of pedicle screws in the surgical management of thoraco-lumbar trauma allows for more rigid and shorter fixation, as compared to more traditional constructs such as the posterior rod and hook construct. The duration of brace wear postoperatively is likewise shorter with the use of pedicle screws. This reduces the period of immobilisation and allows for earlier return to work. Other advantages of rigid internal fixation include prevention of painful, late post-traumatic kyphosis (Fig. 5).

Internal fixation of the spine using pedicle screws has improved the results of surgical treatment of spinal trauma. Previously, surgical management of spinal trauma involved the use of rods and hooks, which required longer segments of the spine to be instrumented compared to present-day pedicle screws systems. The use of pedicle screws has overcome a universally recognised liability in spinal internal fixation: the lack of truly high-quality spinal internal fixation similar to what was available for internal fixation of long bones in the extremities.

Biomechanical tests of pedicle screw constructs have demonstrated the fundamental importance of the bone-implant interface, bone density, and screw pullout strength. The relationship between pullout strength and insertional

torque has been shown, and the improvement in pullout strength obtained by cross-linking and the use of converging screws has also been emphasised.³⁶

Recent studies have found that there is a significant failure rate in terms of instrument fatigue failure and worsening sagittal alignment if the anterior column is not reconstructed one-level above and below the fractured level after pedicle screw fixation.³⁷ Another study by Roy-Camille³⁸ recommended pedicle screw fixation two levels cephalad and caudal to the fractured level.

We now understand that pedicle screws may fail with one-above and one-below construct because of the fact that they are load-bearing devices. Supplemental stabilising methods, e.g. transverse connecting rods, supralaminar or infralaminar hooks, intermediate screws, two-above and one-below construct, or two-above and two-below construct, can be used to enhance the stability of the construct. In very comminuted fractures (e.g. severe burst fractures), additional anterior load-sharing devices can be placed via a separate surgical approach. Commonly used methods for reconstructing the anterior column deficits are structural iliac crest grafts or titanium mesh cage packed with local autogenous graft from the fractured vertebral body. When the anterior interbody graft is in place, posterior compression can be applied to ensure good stability for fusion to take place. At the same time, physiological lordosis and normal loading conditions of the spine can be restored. This will enable the load-sharing system to be recreated.

Anterior decompression and stabilisation play a significant role in the management of thoracolumbar fractures during the past two decades. Early device by Dunn has been superseded by excellent anterior instrumentation systems e.g. Kaneda device, Z plate among others. Anterior instrumentation in the treatment of thoracolumbar fractures has progressed significantly during

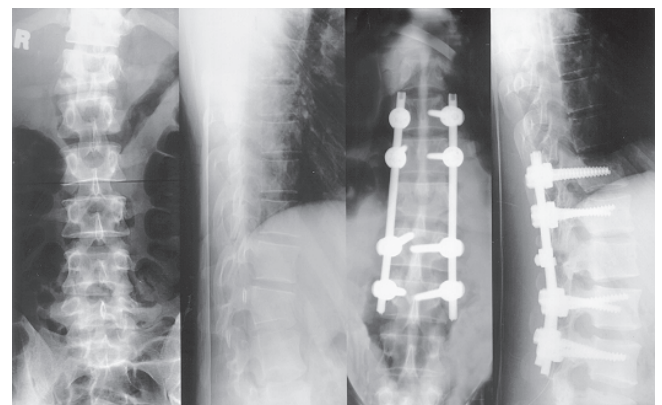


Fig. 5. An unstable burst fracture of T12 vertebra. Posterior instrumentation was performed from T10 to L2. Note the improvement in both coronal and sagittal alignments postoperatively.

the past 2 decades. These fixation systems have evolved to meet the anatomic, biomechanical, and imaging challenges associated with internal fixation of the thoracolumbar spine. For burst fractures from T9 to L3 presenting with bony retropulsion, canal compromise, and neurological deficits, one-stage anterolateral decompressive and stabilisation procedure can be performed. Other indications for anterior surgery included spinal deformity, progressive kyphosis, and late pain.³⁹

The use of titanium mesh cage with local bone graft from the corpectomy to reconstruct the anterior column deficit has been shown to be advantageous in maintaining the anterior column by providing immediate stability while bony healing occurs. It also obviates the need for iliac crest bone grafting and its potential morbidities.

Use of Spinal Instrumentation in Tumours and Infection

Spinal tumours can cause compression of the spinal cord or adjacent nerve roots. Bony destruction can also lead to instability and deformity (kyphosis). Primary tumours are rare, and are treated on an individual basis. The principles are radical excision (total en-bloc vertebrectomy) and stabilisation by bone graft and internal fixation. In recent years, there has been increasing recognition of the value of operative stabilisation of the spine involved in metastatic disease. Many patients are referred late in the course of the disease, when there is extensive disease in the spine and associated neurological deficits. Many of these patients have tried and failed radiotherapy. Joint management in conjunction with oncologists is the best way to improve the outcome and quality of life in these patients.

In recent years, it has been shown that the results of anterior decompression and posterior stabilisation are superior to laminectomy or radiotherapy in the treatment of metastatic disease of the spine. The development of the Tokuhashi prognostic scoring scale (0-12) assists the surgeon in making surgical decisions based on the life expectancy remaining.⁴⁰ Other authors (e.g. Bauer et al,⁴¹ Hart et al⁴²) have also devised a classification system based on the anatomic location of the tumour.

Indications of surgical treatment of the metastatic spine generally include the following: spinal instability, epidural cord compression, significant bony retropulsion leading to cord compression, radioresistant tumours, failed radiotherapy (worsening neurological deficit or tumour recurrence), increasing paralysis, and a fairly long life expectancy remaining. Surgery involves decompression of the spinal cord, excision of the tumour, restoration of the anterior support of the spinal column, and correction of the kyphosis. Because of the limited life expectancy in these patients, immediate stability of the anterior column after

tumour excision can be achieved by spacers or cages (e.g. Harms cage) without waiting for bone fusion to occur. Operative time can also be reduced in this manner. Posterior instrumentation is often needed to provide and restore the physiological posterior tension band. We prefer to perform combined approaches on the same day, as earlier mobilisation and avoidance of the risks of a second anaesthesia are possible.^{43,44} The use of pedicle screws has greatly facilitated the short-segment treatment, including total vertebrectomy, of primary and metastatic neoplasms.³⁶ During the anterior surgery, bleeding can be very heavy.⁴⁵ Therefore, preoperative embolisation is recommended in highly vascularised tumours e.g. metastatic renal cell carcinoma. The stability of the anterior construct (i.e. vertebral body replacement device) can be further enhanced by anterior instrumentation, thereby loading the construct in compression (Fig. 6).

Similarly, spinal infection can cause spinal cord and nerve root compression, instability and kyphosis. Kyphosis arises because of the collapse of the destroyed discs and adjacent vertebral bodies. Cord compression can be caused by one or more of the following: epidural abscess, disc/vertebral body collapse, kyphosis, and instability. Indications of surgery generally include the following: neurological deficits, unknown diagnosis, failed medical treatment, spinal instability, significant cord compression and abscess on imaging studies. The principles of surgical treatment are fairly similar to that of tumours, i.e. debridement of the infective focus, anterior reconstruction, and posterior instrumentation. Though there were initial fears of placing hardware in the infected field after surgical debridement of the vertebral osteomyelitis, one recent study has shown that greater improvement in sagittal alignment was noted for patients with titanium cages implanted anteriorly and for those with posterior instrumentation. Patients who received cages had greater correction of their coronal alignment than for those without. There was also a trend towards fewer postoperative complications for patients who had posterior stabilisation or titanium cages.⁴⁶ Good results in spinal tuberculosis treated only from the front with anterior debridement and instrumentation has also been reported (Fig. 7).⁴⁷

Instrumentation of the Cervical Spine

Internal fixation of the cervical spine originated from simple interspinous wiring, and later evolved into sophisticated instrumentation for the anterior and posterior cervical spine. The indications for internal fixation of the cervical spine include traumatic subluxation/dislocation, spinal stabilisation after laminectomy, and adjunctive fixation after anterior cervical decompression/fusion.

The benefits of instrumentation include rigid stabilisation,

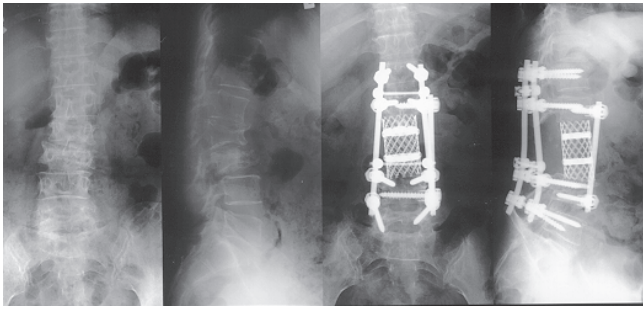


Fig. 6. This patient presented with metastatic breast carcinoma at L2 and L3 vertebrae. She had severe back pain associated with radiation down her legs. Posterior T12 to L5 instrumentation, and decompression of L2 and L3 were performed. This was followed 1 week later by anterior corpectomies of L2 and L3 vertebrae, and reconstruction with Harms cage and anterior instrumentation.

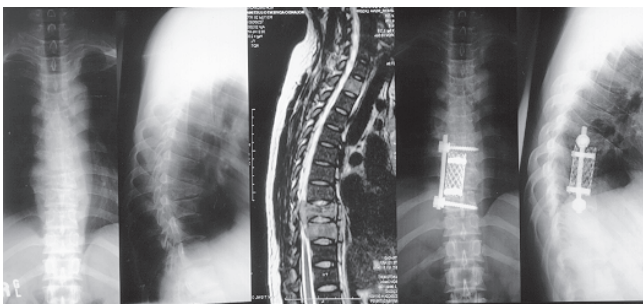


Fig. 7. This patient was diagnosed with spinal tuberculosis of T8 and T9 with cord compression. He presented with worsening neurologic deficits despite anti-tuberculous chemotherapy. Anterior T8 and T9 corpectomies were performed, and the anterior column was reconstructed with Harms cage filled with rib autografts. Anterior instrumentation was added to increase the stability of the reconstruction.

maintenance of alignment, enhanced fusion rates, minimal postoperative external immobilisation, and earlier return to work. The concept of rigid fixation was initially popularised by the AO group in the treatment of fractures of the extremities, and have now been extended to include the spine.

Although anterior fusion of the cervical spine can be performed without internal fixation, it requires postoperative immobilisation in various forms of cervical orthosis for up to 3 months. The halo-vest and Philadelphia collar are the commonly used orthosis for immobilising the cervical spine after surgery. The current consensus is that anterior instrumentation may not matter much in single-level cervical fusion, but improves fusion rate in multi-level fusion of the cervical spine. Various anterior plating systems are currently available in the market, with most employing locking mechanisms for the screws to reduce implant failure (Fig. 8). Recent variations include the capability of placing the screws at variable as well as fixed angles. Some anterior cervical plates also allow dynamisation (not unlike an interlocking nail of the long bone). This property may allow better settling of the graft in between and prevent distraction and non-union of the fusion site.

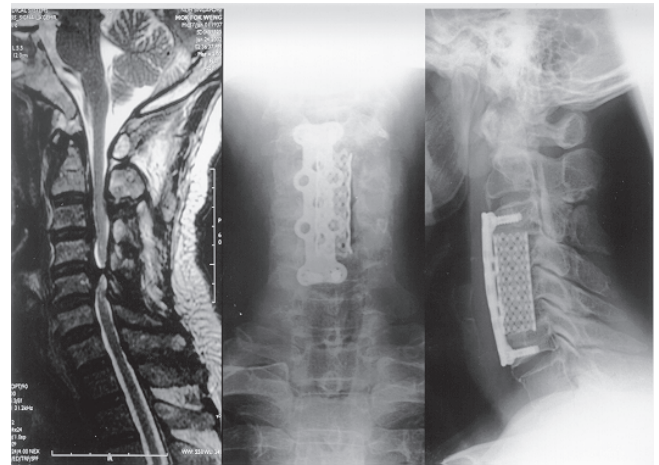


Fig. 8. This patient had cervical laminoplasty performed previously for cervical myelopathy. He was investigated 9 years later for recurrence of his symptoms. MRI revealed extensive ossification of the posterior longitudinal ligament, with severe cord compression at C4 and C5. Anterior C4 and C5 corpectomies were done, followed by reconstruction with Harms cage and cervical locking plate.

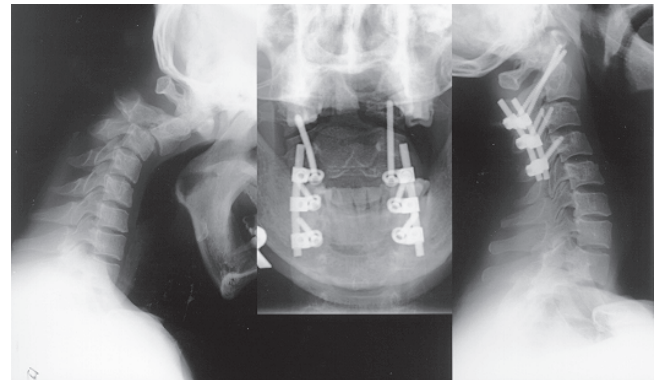


Fig. 9. This patient sustained a type 3 Hangman's fracture, and was initially treated with halo-vest immobilisation at another hospital. The slip gradually worsened and he began to complain of more frequent neck pain. He was eventually managed surgically with C1 to C4 posterior fixation with Cervifix system.

Currently, there are effective segmental fixation systems for posterior cervical fixation. This may reduce the need for cumbersome external immobilisation with devices like the halo-vest. Posterior cervical instrumentation can be subdivided into occipito-cervical (C0-C1), atlanto-axial (C1-C2), and sub-axial fixation (C3-C7).

Occipito-cervical fixation can be achieved by wiring, metal loops (e.g. Ransford loop), and various plate-screw constructs (e.g. Cervifix, Vertex, and Summit). Bone cement can be added depending on the pathologies.⁴⁸

Posterior atlanto-axial fixation (Fig. 9) can be performed with wiring (Gallie or Brook's techniques) and transarticular screws (technique of Magerl).⁴⁹ Recent advances of atlanto-axial fixation are that of a rod screw system described by Harms. The technique involves placing lateral mass screws in the atlas and pedicle screws in the axis.⁵⁰ This technique

is technically demanding and has not yet gained widespread use yet.

Sub-axial cervical fusion (Fig. 9) can be done via wiring techniques (e.g. Bohlman technique of triple-wiring), various plate-screw systems (e.g. Axis plate), and rod-screw implants (e.g. Cervifix). Some of the recent systems are modular, allowing the surgeon various options of internal fixation, e.g. hooks, lateral mass screws, as well as pedicle screws. Some systems also allow the surgeon to extend the instrumentation distally to the upper thoracic spine if indicated.

The use of pedicle screws has been very helpful in the treatment of traumatic and developmental lesions in the cervicothoracic junction.³⁶ Pedicle screws are frequently used from the second to the seventh cervical vertebra by Abumi and at the cervicothoracic junction by Albert. Pedicle screw constructs have been compared favourably with the lateral mass screw constructs, according to a recent biomechanical study.⁵¹

Conclusion

Spinal instrumentation has come a long way over the last few decades. Rigid internal fixation of the spine presents several benefits e.g. earlier mobilisation, shorter hospital stay, improvement in the stability of the spine, and an enhanced fusion rate. Understanding the biomechanics of the spine is crucial when performing spinal instrumentation. Correct preoperative diagnosis, carefully selected patients, attention to surgical details, and a good structured postoperative rehabilitation programme are keys to success in spinal instrumentation.

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