Lumbar Spinal Fusion: Advantages Of Posterior Lumbar Interbody Fusion

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From its inception in 1911, the topic of spinal fusion has seemingly been shrouded in controversy. In that year, Dr. Russell Hibbs performed the first human spinal fusion on a patient with spinal tuberculosis.[1] This spawned a debate over the procedure that led to the denial of Hibbs' membership to the American Orthopedic Association. The procedure (and Hibbs' appointment to the AOA) was validated by the Association after ten years of debate.

The debate over spinal fusions is manifold to this date. The literature is replete with differing opinions regarding the indications, techniques and outcomes of spinal fusions. The topic is further compounded by the fact that the specifics of a spinal fusion are often distinct to the area of the spine fused.

Recognizing the breadth of this subject, the goals of this discussion will obviously need to be limited. Space will not permit a detailed discussion of each pathological entity of every spinal region as it applies to the topic of spinal fusions. We will attempt to review basic principles of spinal mechanics and metabolism as they so apply and to discuss basic indications for spinal fusions. Specific statements of techniques will, for the most part, be confined to lumbar spinal fusions. Advantages of the posterior lumbar interbody fusion (PLIF) will be discussed and the technique described.

BIOMECHANICS AND THE FUNCTIONAL SPINAL UNIT

The ultimate goal of a spinal fusion is to block the motion of one or more functional spinal units(FSU). A FSU consists of two adjacent vertebral bodies and the adjoining disc and surrounding ligaments. The normal pattern of motion at the FSU is essential to the concept of spinal stability. Developmentally, degeneratively, surgically or traumatically acquired disruptions of this normal relationship can lead to spinal instability. White and Panjabi have defined clinical instability as "the loss of ability of the spine under physiologic loads to maintain its pattern of displacement so that there is no initial or additional neurologic deficit, no major deformity, and no incapacitating pain."[2] Once this occurs, the unstable process can be arrested by a spinal fusion. This can be performed in situ or combined with procedures that reduce and stabilize deformations in more normal alignments.

The functional biomechanics of the spine reflect the beautifully designed articulations of each FSU. The latter is, in actuality, a three-joint complex consisting of the intervertebral disc anteriorly and two zygoapophyseal facet joints posteriorly. The study of spinal fracture mechanics has led to the concept of three spinal columns.[3] The anterior and middle columns consist of the vertebral bodies and intervening discs, including the anterior and posterior longitudinal ligaments. The posterior column includes structures posterior to the posterior longitudinal ligament. Due to the sagittal contour of the spine and the location of the line of gravity anteriorly, approximately 90-95% of the compressive loads on the spine are exerted on the anterior and middle columns. The posterior column is exposed to primarily tensile forces.[4,5] These loads may range from 400 N during standing to as much as 7000 N with lifting. The flexion moment exerted on the spine as a result of this force is countered by the soft tissue capsular and ligamentous restraints, as well as by the posterior paraspinal muscles which can exert their own extension moment. These moments act through an instantaneous axis of rotation (IAR) which is felt to lie in the region of the posterior disc in the normal segment.[6] Actually, the mechanics of the normal FSU involve the complex coupling of motions through six degrees of freedom in three dimensions.[7]

Much of the ability of the FSU to function without failure depends upon a well-hydrated intervertebral disc. The fluid-filled nucleus pulposus maintains disc space height, which in turn, keeps the surrounding soft tissue constraints on tension, maximizing their resistance to displacement. With normal disc distention, the normal articular relationship of the facets is maintained. Moreover, in this state, the facets are exposed to very little shear stress, since force lines around a relatively stationary IAR are tangential to the facet joints. The normal disc height also helps ensure a patent neuroforamen for the exiting nerve root.

The incompressible hydrated nucleus also functions as an efficient load transfer system. Axial compressive loads are absorbed by the nucleus pulposus, which then transmit this stress to the radial annular fibers as tension that is readily dissipated in the inner annulus fibrosa. Very little compression is, therefore, exerted on the vertebral endplates, facets or annulus.(Figure 1a)

Thus, in the normal spine, load is dissipated, displacement is restrained, and the neural tissue is protected by elements of each of the three columns of the spine. This is the essence of a stable spine.

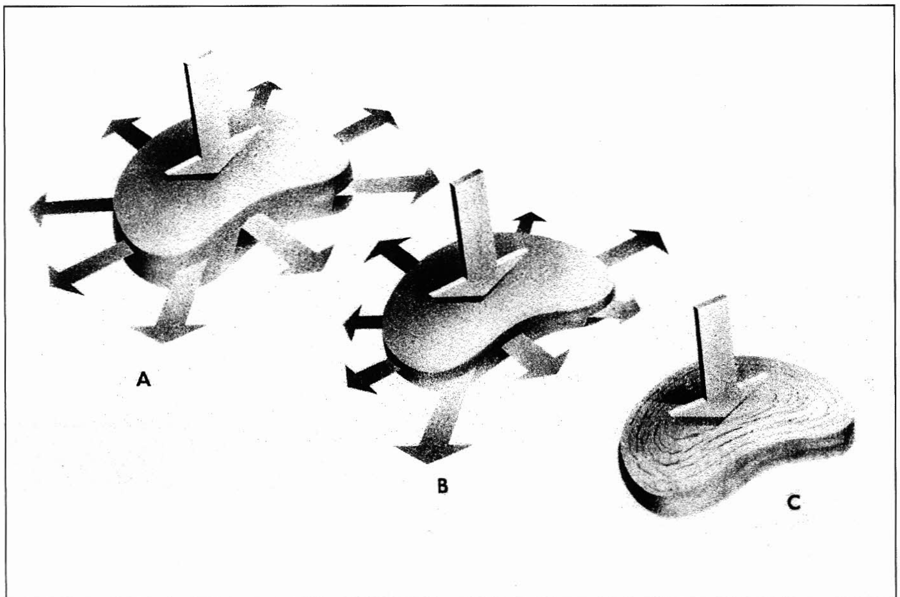

Figure 1. Distribution of forces in the normal and abnormal disc. A. When the disc functions normally, as in early decades of life. the nucleus distributes forces of compression and tension equally to all parts of the annulus. B. With degeneration, the nucleus no longer functions as a perfect gel and the forces transmitted to the annulus are uneven. C. With advanced degeneration of the nucleus, the distribution of forces to the annulus from within is completely lost, and the nucleus now acts as a solid rather than a liquid. (Rothman RH, Simeone FA and Berlin PM: Lumbar disc disease. In The Spine, Rothman and Simeone, eds. Second Edition. WB Sanders, Philadelphia, 1982, p.522. Reprinted with permission.)

THE UNSTABLE SPINE

It is relatively easy to appreciate how acute disruptions of the spine can create an unstable situation. There can be little doubt as to the instability of a fracture-dislocation of the spine. Less obviously unstable fracture patterns have been well simulated in extensive biomechanical tests that have actually formed the basis of the three column concept of spinal stability.[3,8] Tumors and infections typically destroy the anterior and middle columns to an extent that instability is apparent and often noticeably progressive. The diagnosis of spinal instability, as defined above, can be fairly well established in these conditions. While the mere presence of these conditions in the spine does not obligate a physician to operative intervention, the diagnosis of an acutely or progressively unstable spine will, in most instances, lead to surgical treatment. This will often entail decompression of neural elements and reduction of spinal alignment. Spinal fusion is necessary to maintain reduction and to prevent progressive deformity. In situations of instability, the use of spinal fixation to prevent displacement while boney fusion matures is fairly well established.

While spinal fusion plays a relatively clear role in the treatment of instabilities secondary to fractures, tumors, infections and deformities such as progressive or high-grade scoliosis, it must be recognized that these conditions make up a minority of the cases for which the roughly 70,000 spinal fusions per year are performed.[9] A large percentage of spinal fusions are performed for degenerative instabilities.[10] Primary degenerative instabilities arise from motion segment dysfunction secondary to the process of disc degeneration, in which the nucleus pulposus undergoes a gradual dehydration. With the loss of disc turgor, the mechanism whereby compressive loads are distributed as tensile forces to the surrounding annulus become deficient. The annulus will, therefore, be increasingly exposed to compressive loads, a situation for which the annular fibers were not designed to withstand. Annular tears develop.(Figure 1c) With the loss of hydraulic disc pressure, the disc space will narrow and the weakened annulus will circumferentially bulge and/or focally prolapse. As the disc space narrows, the facet joints sublux, often with a retrolisthesis of the superior body. The neuroforamen is narrowed by the collapsing disc space, the encroachment of the superior facet and the laterally bulging annulus. This may cause lateral nerve root impingement of the exiting nerve root, unlike the irritation of the traversing nerve root in a classical posterolateral herniated disc.

With disc dysfunction, the IAR may now shift with motion.[6] The facet joints are now exposed to shear stresses and are subject to arthrosis. Resultant spurs further compromise the spinal canal. Facet degeneration and subluxation compromise the articular and capsular stability. The other surrounding soft tissue constraints to hypermobility which function while under tension have now become lax with disc narrowing and loose their mechanical advantage. The body reacts to the resulting segmental instability by laying down osteophytes.

The pathoanatomical changes outlined above have been well-documented and described as occurring in three phases by Kirkaldy-Willis.[11](Figure 2) Knutsson recognized in 1944 that degenerated lumbar discs often exhibited increased translation on flexion-extension Xrays.[12] It has been stated that in order to define instability, 4mm of static displacement at L3-4 and L4-5 was necessary for accuracy due to intra- and inter-observer errors, while 5mm or more was needed at L5-S1.[10] Boden and Wiesel found no more than 3mm of dynamic translation to be abnormal.[13] Dupuis noted increased angular motions of degenerated discs on flexion-extension.[14] Mcnab felt that traction spurs at the endplates adjacent to the disc indicated segmental instability.[15]

It is not difficult to imagine how a degenerative, collapsing disc (often referred to as being vertically unstable) can lead to a primary instability with abnormal rotational, translational or angular motion. Studies have documented these changes in the degenerative spine.[10,12,13,14,16,17] One must realize that not all of these changes represent measurable hypermobility. With advancing degeneration, the spine goes through a restabilization phase.[11] Marginal osteophytes may limit motion in this stage of the degenerative process. In vitro studies have documented decreased flexion/extension and lateral side-bending in such disc segments.[18,19]

What may be difficult, therefore, is for a physician to make a clinical judgment as to whether a patient's X-ray changes correlate with his symptoms. While it may be possible to experimentally document changes in coupled motions about a shifting IAR, the practitioner can most often make a much more simplistic assessment. The degenerative changes are often readi-

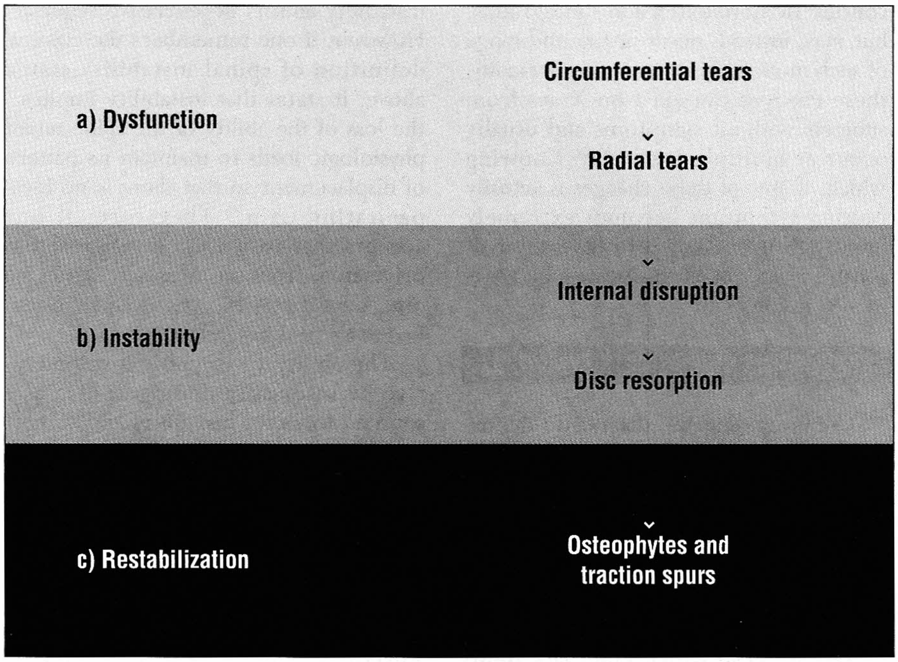

Figure 2. The progressive degenerative changes in the annulonuclear complex of the intervertebral disc overlaid by the three phases of the degenerative process. (Dupuis PR: The natural history of degenerative changes in the lumbar spine. In Lumbar Discectomy and Malinectomy, Watkins and Collis, eds. Aspen, Rockville, 1987, p3. Reprinted with permission.

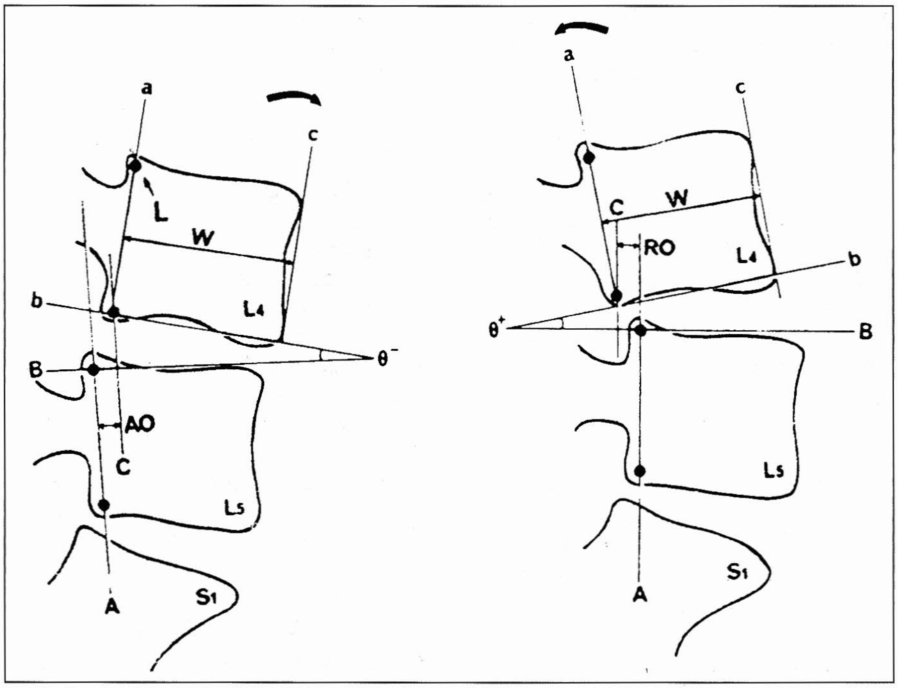

Figure 3. Reversal of disc angle or "clam-shelling" on flexion and extension X-rays may indicate segmental instability. (Dupuis PR, Young-Hing K, Cassidy JD, Kirkaldy-Willis WH; Radiologic diagnosis of degenerative lumbar instability. Spine 10: 262-276, 1985. Reprinted with permission.)

ly evident, and there are guidelines for excessive translation[12,13] and angulation (reversal of disc angle or "clam-shelling").[14](Figure 3) However, as noted above, these changes may actually decrease with further degeneration. There has also been some suggestion that clinical instability does not occur or is not detectable at the extremes of sagittal motion, i.e.. that which is measured on routine flexion/extension radiographs, but may, instead, occur at the mid-range of such motion.[20] Even more importantly, these changes can exist on Xrays from subjects without symptoms and usually occur at multiple levels.[21,22] Knowing which, if any, of these changes is actually causing symptoms becomes extremely important if one hopes to have any reasonable chance of alleviating pain by a segmental fusion.

CORRELATING STUDIES WITH SYMPTOMS

Compounding the diagnostic dilemma is the fact that if, indeed, these changes do cause symptoms, the patients' complaints are often those of non-radicular low back pain. This is due to the fact that the nociceptive receptor is often not the primary nerve root, but, instead, small branches of the sinuvertebral nerve which innervate those pathoanatomical structures that develop as a sequel to disc degeneration. Complaints of dermatomally-referred leg pain can be of diagnostic assistance if the dermatome implicates a spinal segment with obvious degenerative changes that may be affecting the exiting nerve root at that level.

An interesting subset of degenerative instabilities is the entity of disc disruption syndrome, or internal disc disruption(IDD). This is a nonprolapsing disc disorder described by H.V. Crock in which the internal structure is disturbed, theoretically by trauma.[23] Unlike degenerative disc disease, the radiographic changes seen in the former disorder do not typically develop in IDD. While the internal derangement was previously diagnosed solely by discography, The T2 weighted image of MRI is a sensitive indicator of the metabolic disc changes that are thought to occur in this condition.[24] It is felt that the pain from such discs occurs secondary to degraded protein catabolites released into the endplate micro circulation. Due to the fact that the classical teaching of disc disorders has focused on the mechanical derangements of disc instability and nerve root compression as painful stimuli, some may find it difficult to think in terms of biochemical pathology. Such pathways are becoming increasingly recognized as possible sources of spinal pain.[25] Others may question as to whether this condition truly represents a spinal "instability", due to the fact that X-ray changes are often absent and the condition will often not develop vertical instability and its degenerative sequelae. However, if one remembers the classical definition of spinal instability stated above, it states that instability implies " the loss of the ability of the spine under physiologic loads to maintain its pattern of displacement so that there is no incapacitating pain." Therefore, if one accepts that pain can be diagnosed as originating from an internally deranged disc, then it may be appropriately classified as a spinal instability.

The ability to diagnose a degenerative or internally deranged disc as a source of painful instability and to correlate these findings with a patient's symptoms are key concepts in the debate over whether such patients are viable candidates for spinal fusion. These changes, as opposed to fractures, infections and malignant or destructive tumors, may exist to varying degrees in a majority of the population who do not complain of symptoms and may be detected on studies, including MRI scans, in asymptomatic subjects.[26] This, of course, does not preclude the possibility that such "subjects" may become "patients" complaining of discogenic pain at some point in their lives. Whether or not such patients with chronic, disabling pain are offered the option of surgical stabilization via lumbar fusion depends, in large part, upon whether his or her physician is aware of the entity of discogenic pain and has the wherewithal to diagnosis it. We feel the literature strongly supports this clinical entity, as well as the ability of provocative discography/CT to aid in its diagnosis and selection of appropriate candidates for spinal fusion.[19,23,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43] We agree with the indications for discography as put forth in the recent position paper on the subject by the North American Spine Society.[44] According to this statement, discography is a justified study prior to consideration of fusion in patients with disabling low back pain (with or without leg pain) of more than four months that has failed to respond to aggressive conservative therapy.

THERAPEUTIC CONSIDERATIONS

This brings up a point that cannot be too strongly emphasized, i.e., most patients with symptoms secondary to degenerative lumbar instabilities can be successfully treated with nonoperative treatment. The cornerstone of such treatment is dynamic lumbar paraspinal strengthening. The goal of treatment is to get symptoms into a tolerable range and to return the patient to some functional activity. Returning the patient with such symptoms to "normal" pain-free existence may not be realistic, especially if they were engaged in heavy labor. If therapy and activity/job modifications can allow the patient's symptoms to lessen into a tolerable range, then such patients should be encouraged to recognize this as a therapeutic success. If the degree of modifications to obtain this status is so severe as to be inconsistent with a patient's quality of life, or if no such modifications are able to lessen the patient's symptoms (along with failure of all other forms of conservative therapy), then one can consider surgical options.

If a patient has failed to improve with time and therapy, there are several very important factors to consider prior to embarking on a surgical work-up for possible fusion. Firstly, in a patient who fails to respond to adequate treatment in a reasonable period of time or who exhibits any non-mechanical component to his complaints, e.g. night or rest pain or constitutional symptoms, e.g. fevers/chills, night sweats, unexplained weight loss or abdominopelvic pain, one must be very careful to rule out all other sources of pain that may mimic benign disc disease.

Having considered such possibilities, it is prudent to evaluate the patient for significant non-organic physical signs.[45] While these physical inconsistencies do not mean that a patient does not have an organic basis for his pain, they do imply a functional disorder which may complicate the result of a perfectly performed surgical procedure. The MMPI is routinely used to screen patients prior to such extensive procedures. We believe that it is incumbent on the spinal surgeon to have a basic understanding of the non-physiological aspects of back pain and to address them in the pre-operative evaluation. In an effort to identify those patients that because of non-spinal conditions would have a high likelihood of not optimally responding to lumbar arthrodeisis 245 consecutive patients of the senior surgeon (L.A.W.) were examined. All of these patients had undergone an arthrodesis combining the use of a posterior-interbody and posterior-lateral fusion using pedical screws and V.S.P. plates. The goal was to identify the most difficult patients patients to improve or heal by this surgery.

A well delineated group of patients were identified and have since been referred to as patients having the Black Widow Syndrome. In nature the female Black Widow entices the male to help her with an infertility problem and subsequently eats him; in the Black Widow Syndrome the surgeon is enticed by the back patient to correct a spinal problem but the surgeon is subsequently "eaten" and the patient relates not improving. In the study, the most difficult patients had the following constellation of findings now referred to as the Black Widow Syndrome: 1) a married woman, 2) scored above two standard deviations on the MMPI-2 for hysteria and hypochondria, 3) scored a four or higher for sexual activity on the Oswestry function test (they reported that ...) 4) smoked cigarettes, 5) had an active Workers compensation or liability claim. Individually the above factors have been discussed as being detrimental to spinal surgery results. However, when they appear in the above combination, we feel it can be devastating to results. When operating on a patient with the combination the following is recommended: 1) the patient should be counseled that they have a particularly severe risk factor, 2) a special handwritten statement documenting that the surgeon has informed the patient that even with the best results, the surgeon predicts that the patient will continue to have a substantial amount of pain. Following this recommendation appears to help in returning the patient to a higher level of function post-operatively.

Before considering surgery, one should also consider the extent of pathology on the patient's Xrays. One should only rarely consider a lumbosacral reconstruction in the face of extensive multilevel lumbar spondylosis. Ideally, the pathology should be limited to no more than 2-3 disc segments with demonstrably normal adjacent discs. If it were necessary to fuse the entirety of the lumbar spine, one should consider extending the fusion into the lower thoracic spine, thereby avoiding the stress concentration of the unfused thoracolumbar junction between the relatively stable thoracic segment and the newly fused lumbar spine. One should also be leery of fusing a select few symptomatic segments of the entirely spondylotic spine even if the adjoining segments did not reproduce typical pain on provocative discography. The stresses transferred by the newly fused segments to these structurally unsound discs have a high probability of inducing symptoms in these levels. One should strive to have a buffer of structurally sound, non-symptomatic discs above the reconstructed levels.

Lastly, before deciding whether or not a patient is a serious candidate for such extensive surgery, the patient's medical history should be found stable enough to be able to tolerate the procedure itself. Furthermore, smokers have up to five times the incidence of nonunion as compared to nonsmokers. Efforts should be made prior to surgery to help such patients discontinue their smoking habit.

It is important to remember that, except for a progressive neurological deficit, bowel or bladder dysfunction or certain other conditions such as tumors, infection and some fracture patterns, the surgery for the vast majority of degenerative conditions is entirely *elective* - for both the patient and the doctor! By far the most important factor that affects surgical outcome in this situation is patient selection. Any of the above-mentioned factors should make the surgeon think twice before considering surgical options.

INDICATIONS FOR LUMBAR SPINAL FUSION

The indications for lumbar spinal fusion may be broadly categorized as "instabilities", as per Frymoyer.[20](Table 1) We have specifically discussed the etiology of the subclass of primary degenerative instability.(Table 2) Instabilities may also

Lumbar Segmental Instabilities

I. Fractures and fracture-dislocations
II. Infections involving anterior columns
   A. With progressive loss of vertebral body height and deformity despite treatment with antibiotics
   B. With progressing neurologic symptoms despite treatment with antibiotics (if accompanied by progressive loss of vertebral body height and deformity)
III. Primary and metastatic neoplasms
   A. With progressing loss of vertebral body height and deformity
   B. With progressing neurologic symptoms not resulting from direct tumor involvement of the spinal cord, cauda equina, or nerve roots (that is, caused by progressive loss of vertebral body height and deformity)
   C. Postsurgical (after resection of neoplasm)
IV. Spondylolisthesis
   A. Isthmic spondylolisthesis
      1. L5-S1 progressive deformity in a child, particularly with accompanied by radiographic risk signs (this lesion is rarely unstable in adults)
      2. L4-L5 deformity (probably unstable in adults)
V. Degenerative instabilities
VI. Scoliosis (any progressive deformity in a child—subclassified by the criteria of the Scoliosis Research Society

Table 1. **Reprinted with permission.[10]**

Degenerative Segmental Instabilities

Primary Instabilities
   Axial rotational instability
   Translational instability
   Retrolisthetic instability
   Progressing degenerative scoliosis
   ? Disc disruption syndrome

Secondary Instabilities
   Post disc excision—subclassified according to the pattern of instability as described under primary instabilities

Post decompressive laminectomy
   Accentuation of pre-existent deformity
   New deformity, i.e., no deformity existed at the time the of original decompression. Further subclassified as for primary instabilities

Post spinal fusion
   Above or below a spinal fusion, sub classified as a primary instabilities
   Pseudoarthrosis

Table 2. **Reprinted with permission.[10]**

occur secondarily following decompressive procedures for lumbar canal stenosis or post-discectomy. It has been noted that risk of iatrogenic instability following decompressions increases if more than 50% of both facets or one entire facet is resected.[46] In this situation, fusion at the index procedure is indicated. Fusion at the time of decompressive laminectomy for stenosis has also been recommended if degenerative spondylolisthesis exists at the time of surgery.[47] Other relative indications for primary fusion at the time of decompressive laminectomy include a relatively young patient with well-maintained disc heights, multiple level decompressions and discectomy at the time of decompression.[9,20]

We do not routinely perform primary fusion at the time of discectomy unless a significant component of the patient's preoperative pain is low back pain(LBP). Cloward recommended routine interbody fusion primarily for all disc herniations.[48] Others have reserved this recommendation for disc excision at L4-L5, due to the purported incidence of troubling post-op LBP following discectomy without fusion at this level.[49] While our own anecdotal experience does seem to bear this out, the majority of the literature does not recommend routine fusion at the time of discectomy. We do, however, tell our patients who are undergoing discectomy that the incidence of post-op LBP following discectomy may range from 15-60% and that this may necessitate a fusion procedure at a later date.[50,51] Therefore, if the primary complaint involves significant LBP, a laminectomy/discectomy alone should be avoided and decompression should be combined with primary fusion.[52] Conversely, radicular leg pain with minimal LBP secondary to disc prolapse can most often be surgically treated by laminectomy/discectomy alone, as stated above. An instance where a patient with primarily leg pain may need to be treated with a fusion procedure is a situation wherein the nerve root compression is not due to a typical posterolateral disc herniation, but rather secondary to far lateral impingement as a result of "up-down" lateral stenosis of the neuroforamen in association with disc space collapse. The disc will indeed bulge as well, usually circumferentially, and will contribute to the lateral nerve root compression. An annulotomy/discectomy of this bulge will have approximately a 44% chance of relieving the patient's leg pain.[53] A better method of relieving this nerve root is to perform a total discectomy, disc-space re-elevation and interbody fusion. Other instances in which a patient with an herniated disc causing greater leg pain than LBP may be considered a candidate for primary fusion are when the affected disc level has an associated neural arch defect or when the herniation is extremely large and upon its removal very little disc will remain for further stability.

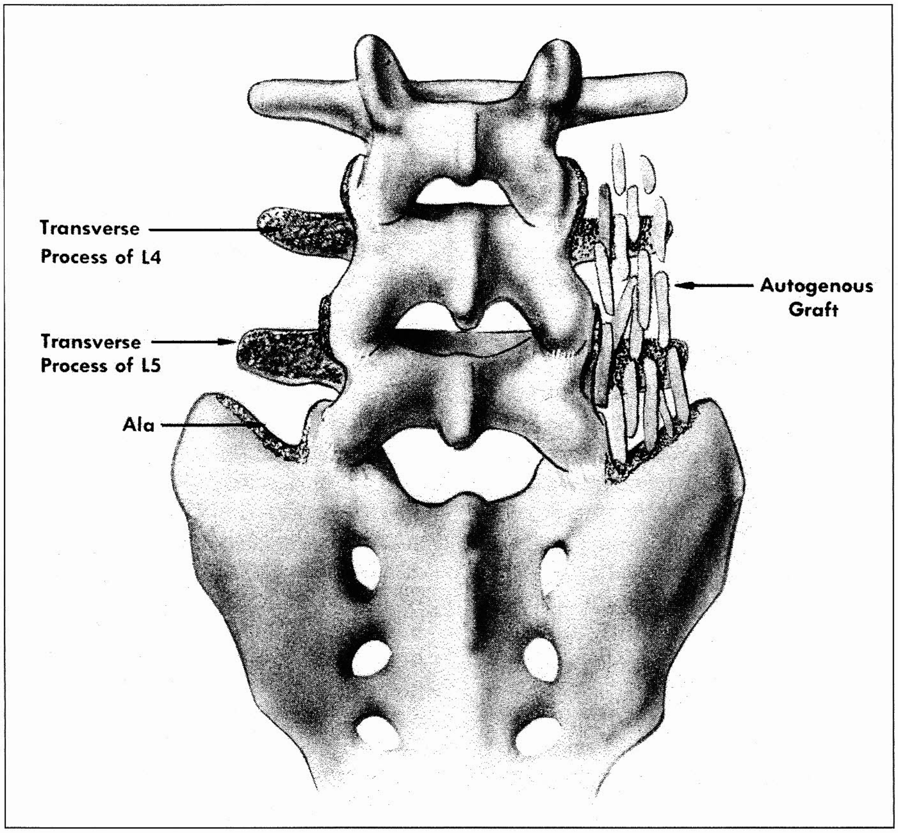

Figure 4. Area of the bed of raw cancellous bone for a lateral spine fusion from L4 to the sacrum. The bed is shown on the left and the graft material is in place on the right. In actuality a much larger volume of graft material is utilized. The bed indicates the transverse processes, the ala of the sacrum, the lateral portion of the pedicle and the lateral portion of the superior articular facets. (Rothman RH, Simeone FA and Berlin PM: Lumbar disc disease. In The Spine, Rothman and Simeone, eds. Second Edition. WB Sanders, Philadelphia, 1982, p.617. Reprinted with permission.

NOT ALL FUSIONS ARE CREATED EQUALLY

At the outset of this discussion, we made note of the fact that the topic of spinal fusion, especially when used in the treatment of degenerative conditions, is very controversial. This is due to many reasons, some of which have been mentioned previously. Another reason that controversy may exist is that the literature contains influences from both the orthopedic and neurosurgical subspecialties. Orthopedists perform five times as many fusions as their neurosurgical counterparts, whose training has tended to de-emphasize the concept of the disc as a joint.[54] The literature that does analyze spinal fusions lacks convincing randomized prospective studies comparing similar patient populations with selected fusion techniques. Some articles cast doubt about the effectiveness of spinal fusion after reviewing many different articles describing a multitude of techniques.[54,55] Other reviewers have noted a lack of correlation between fusion, pseudoarthrosis and clinical outcome.[56,57] However, more recent articles have tended to establish this correlation.[52,55,58,59,60,61]

Perhaps the biggest reason that a failure to reach a consensus regarding the efficacy of lumbar spinal fusion has plagued the literature is that not all spinal fusions are created equally. Lumbar fusions may be performed anteriorly, posteriorly, posteriorlaterally or circumferentially(both anteriorly and posteriorly). They may or may not be supplemented with instrumentation or electrical stimulation. Spinal instrumentation may include wires, hooks, facet screws, bone screws(inserted into the vertebral bodies and pedicles), plates and rods. Fusion material may include autograft, allograft and xenograft and may be supplemented with bone substitutes or demineralized bone matrix. Combine these many variables with the fact that surgical results are dependent upon technique and the many patient-related factors discussed above and it is no wonder that the results of spinal fusion are difficult to assess.

We feel that if the results of a spinal fusion are to be maximized, the surgical approach should address the area of spinal pathology. Certain conditions will tend to affect specific areas of the spine. Some modes of spinal trauma will selectively injure posterior elements and spare the anterior columns. Infection or tumors will often affect only the anterior spine. When instability arises from such select areas of the spine, it may be perfectly indicated to limit a fusion to that area alone. In contrast, the pathology that occurs secondary to disc degeneration will most often affect both anterior and posterior spinal columns.

POSTEROLATERAL LUMBAR FUSION

One of the most commonly performed types of lumbar fusions performed today is the posterolateral (intertransverse) fusion, as first described by Campbell in 1939.[62](Figure 4) This technique has been found to be much more stable in axial rotation and lateral bending as compared to the previously fashionable posterior fusion in that it provides a greater area moment of inertia.[63] It also provides more bone graft surface area, as compared to the posterior fusion and does not have the problem of iatrogenic stenosis that was commonly seen following posterior fusions.

The posterolateral fusion mass is, however, placed along the posterior column of the spine. As one recalls from previous discussions, this area is predominantly exposed to tensile forces. According to Wolff's law, compression is a better stimulus for bone production. This, along with the motion across an uninstrumented posterolateral fusion mass, may account for the fact that the pseudoarthrosis rate for such fusions may be as high as 60-85%.[59] We feel that the recent literature has clearly shown that spinal instrumentation can increase the fusion rate to over 90% in these procedures.[58,59,60,61,64] Most of these reports have evaluated the performance of pedicle-based fixation systems. Spinous process or sublaminar wires and sublaminar hooks, which have a long history of use in thoracolumbar deformity surgery, are often of less value in lumbar degenerative conditions which frequently involve laminectomy. Furthermore, these devices exert limited control of the multiplanar forces exerted on the spine. Transpedicular screw-based devices, however, resist loads of any type by controlling the "force-nucleus" of the FSU.[65] Because of the rigidity so provided, the number of segments fused can be kept to a minimum, extensive decompressions can be performed and significant deformities can be reduced. There is some concern about excessive rigidity of these devices and device-related osteopenia has been observed in the vertebral bodies transfixed by this hardware.[66] Others caution that excessively rigid implants may transfer excess stress to adjacent levels causing accelerated degeneration, terming this phenomenon "transitional syndrome."[67] The clinical significance of this is unknown. It has been fairly well-established that rigid fixation increases the rate of fusion as well as the rigidity of the fusion mass itself.[61,66,68] The efficacy of instrumented posterolateral fusions used in the treatment of patients with discogenic LBP secondary to degenerative instabilities has been documented in recent literature.[31,43,58,59,60,61,64]

It is also noteworthy that in many of these studies, as well as in others, a comparison of postoperative pain scores often did not differ between patients with solid posterolateral fusion versus those with pseudoarthrosis.[31,43,60,64,69] A recent article in *The Backletter* states that up to 50% of instrumented posterolateral fusions fail to relieve patients' symptoms.[70]

We believe this is due, at least in part, to residual motion and loading across the disc that occurs after solid instrumented posterolateral fusions. Nachemson and Morris showed that posterior spinal fusions did decrease, but did not completely eliminate, load and motion across the disc.[71] Goel found that after bilateral screw-plate fixation, posterior plates transmitted 20% of applied load, as compared to 4% that was distributed across the facets in a normal spine.[5] Therefore, while the anterior column transmitted 96% of the load in the normal spine, following posterior plating 80% of the load was still applied to the anterior column. White and Panjabi have also shown that even with solid fixation of all of the posterior elements, motion may still exist across the disc space secondary to the elasticity of the pedicles.[2]

ANTERIOR COLUMN (INTERBODY) FUSIONS

Therefore, we agree with findings that suggest that posterolateral fusions alone may be insufficient in the treatment of discogenic pain and that anterior fusion provides greater rigidity and directly blocks intervertebral motion.[6,72] Weatherley followed a small group of such patients who had continued pain after apparently solid posterolateral fusion. Concordant discography (with reproduction of the patient's typical pain) from the disc within the fused segment was followed by anterior disc fusion. In all those who submitted to the procedure, anterior fusion consistently relieved the patient's pain.[69]

We have had a similar experience within our own practice and feel strongly that if discogenic pain is to be treated surgically by a fusion procedure, that procedure should address the source of the pain directly and fusion of the anterior column should be performed. This is not to say that the posterolateral fusion as an isolated procedure cannot be used without some success. However, even if one examines articles that note the procedure's utility, failure rates of nearly 30% are reported with solid posterolateral fusion, while nonunion always led to clinical failure.[60] In this same report, the pseudoarthrosis rate, although decreased when compared to non-instrumented fusions, was still 16% with fixation and the screw-breakage rate was five times that of a comparable series in which instrumented posterior lumbar interbody fusions were performed.[73] This latter finding most likely correlates with the residual motion that exists across the unfused disc which is "shielded" by a posterolaterally fixed and fused spine. The loads and motion to which the disc remains exposed can cause residual pain and recurrent herniation. We, therefore, feel that pain secondary to degenerative disc disease, when treated surgically, is best treated by fusing the disc itself.

INDICATIONS FOR PLIF

The anatomical changes that result from the vertical instability of the narrowing, degenerative disc include 1) circumferential disc bulging, 2) approximation of the lamina with buckling of the ligamentum flava, 3) narrowing of the intervertebral canal with "up-down" lateral stenosis, 4) subluxation of the facet joint with arthrosis and retrolisthesis and 5) "de-tensioning" of the passive ligamentous restraints which, along with the other changes, leads to segmental instability. The surgical approach for the treatment of these changes should decompress the neural tissue, distract the vertebral bodies and stabilize the motion segment. A discectomy can decompress the neural elements, but it cannot distract the disc space or stabilize the motion segment, and may hasten the disc narrowing. A laminectomy can decompress the neural elements, but also cannot distract the disc space and may very well increase segmental instability. A posterolateral lumbar fusion can (at least partially) stabilize the motion segment, but cannot decompress the neural elements or re-elevate the disc space. An anterior lumbar interbody fusion (ALIF) can stabilize the motion segment, but cannot decompress the neural canal and has limited ability to distract the disc space.[74] While some have reported good results from ALIF for IDD, our own experience is that without some form of fixation, the grafts tend to collapse and the incidence of nonunion is high. Techniques are being developed using structural interbody "cages" into which bone graft can be inserted in an attempt to give mechanical support while allowing anterior boney ingrowth to occur through the cages.[78] For non-prolapsing IDD, ALIF followed by separate posterior fixation and posterolateral fusion is a very reasonable approach. In our hands, for this and other degenerative instabilities, the ideal surgical procedure is the posterior lumbar interbody fusion and plating, the "PLIF and plates" procedure, as popularized by Steffee.[65] This procedure accomplishes all of the reconstructive goals listed above through one surgical approach.

ADVANTAGES OF PLIF

The PLIF and plates fusion offers several distinct advantages over an instrumented posterolateral fusion. Firstly, the procedure involves (near)total disc excision. This directly removes the source of discogenic pain and eliminates the possibility of recurrent disc herniation. This also allows the collapsed disc space to be re-elevated, thereby decompressing lateral nerve root impingement by opening up the neuroforamen and reducing the lateral annular bulge by restoring the annulus to tension. The total discectomy allows deformities, e.g. degenerative scoliosis and spondylolisthesis, to be temporarily destabilized so that realignment can be regained through disc elevation and manipulation of the instrumentation. Stability is then reestablished through anterior fusion and rigid posterior fixation and grafting.

The interbody graft is at better biomechanical advantage than a posterolateral graft. The former graft is under compression, whereas posterolateral graft is exposed to tension. According to Wolff's law, the stimulus of compression enhances bone production. This allows an enhanced rate and incidence of fusion following an interbody graft. The interbody graft also has a large, well-vascularized surface area for fusion and, when properly prepared, allows for good vascular ingrowth into the fusion mass. When combined with a posterolateral fusion, a PLIF results in a 360 degree fusion around the spinal canal -a very stable fusion construct. This stability allows for wide decompressions, including excision of the facet joints which, if retained, can be a source of further pain.

Moreover, the difficulty of determining the fusion status following a posterolateral grafting is well documented, especially after posterior instrumentation.[79] Whereas this may also be difficult after an interbody fusion, we find it easier to assess an interbody graft for fusion status than an instrumented posterolateral fusion.[80] It may also be true, as advocated by Collis, that an interbody non-union may give adequate structural support so as not to affect the clinical result.[81] This is in contrast to reports of instrumented posterolateral fusions in which nonunions always led to clinical failure.[60]

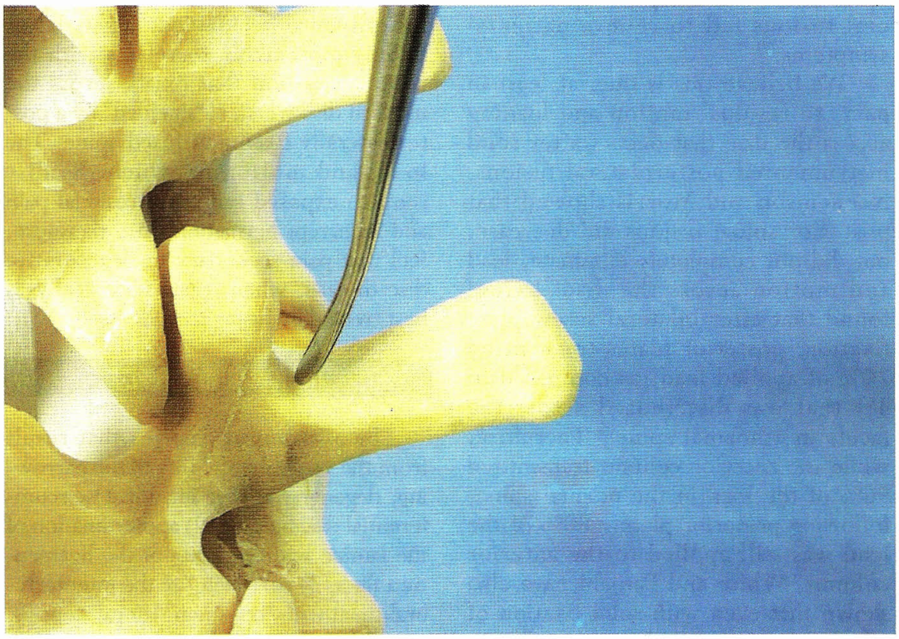

Figure 5. The entry point into the pedicle is located at the confluence of three ridges from the pars interarticularis, the superior facet and the transverse process. This lies most often along a line that bisects the transverse process.

SURGICAL TECHNIQUE OF INSTRUMENTED PLIF

The patient is placed prone on a frame that will allow the abdomen to hang freely, thereby decreasing pressure that is transferred to the epidural venous plexus in an attempt to minimize blood loss. For similar reasons, use of hypotensive anesthesia is critical. The patient is also positioned so as to minimize hip and leg flexion. It has been shown that frames such as the Hastings, Andrews and C.H.O.P. 4-poster, on which patients' hips may be flexed from 60-90 degrees, can decrease lumbar lordosis by approximately 50%.[82] We feel it is essential to maintain or reestablish normal lumbar lordosis during lumbar fusions, especially multilevel fusions, so that transfer stresses to unfused segments can be minimized. The head is kept in neutral position with no pressure on the eyes. Boney prominences are well-padded and arm abduction is kept below 90 degrees to minimize stretch on the brachial plexus.

A single midline approach is performed. The paraspinal muscles are dissected and retracted laterally so as to expose transverse processes of the segments to be fused. If large-bladed self-retaining retractors are used, they must be loosened frequently to minimize tissue necrosis. A midline decompressive laminectomy is performed and carried proximally to the inferior hemilamina of the most superior level to be fused. Care is taken to keep the supra and interspionous ligaments intact between the remaining spinous process of the most superior fused segment and the next proximal unfused level. The facet joint capsules of the segments to be fused are removed. Quite frequently a total facetectomy of the inferior facets and a partial facetectomy of the superior articular facets are performed bilaterally at each fusion level. Subtotal facetectomies may be performed alternatively. The thecal sac is widely exposed at this point and any subarticular boney stenosis can be decompressed.

At this point, the spinal implants are inserted. As stated above, we feel that the strongest fixation available is provided by bone screws inserted into the vertebral pedicles. The morphometric characteristics of the thoracolumbar pedicles have been well documented.[83] Any question as to the adequacy of the size of the pedicle or any anatomical variance should be evaluated by preoperative CT scanning in the plane of the pedicle. Also, stability of the fixation can be adversely affected by osteoporosis and if there is any question of this, one should consider preoperative assessment of the severity of this condition. If one should encounter weak fixation secondary to osteoporotic bone during screw insertion, the screw-bone interface can be strengthened by supplementing the prepared pedicle with bone chips or PMMA. The latter method can cause injury to the neural elements if cement extrudes into the canal during insertion.

The usual entry point into the pedicle is found at a point of confluence of three small ridges from the pars, the superior

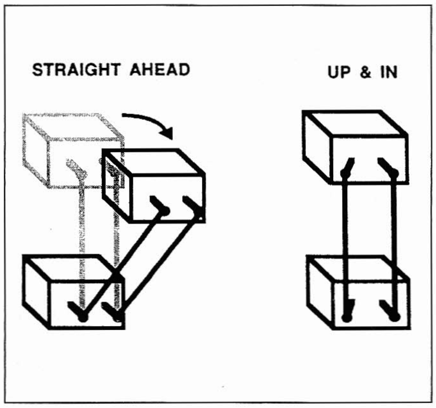

Figure 7. Convergent screw placement helps prevent lateral collapse or parallelogramming, as opposed to straight ahead placement. Cross-linking of the longitudinal members may also prevent such collapse. (Krag MH: Biomechanics of transpedicle spine fixation. In: Weinstein JN Wiesel S. eds. The Lumbar Spine, Philadelphia: WB Saunders, pp 916-940. Reprinted with permission.)

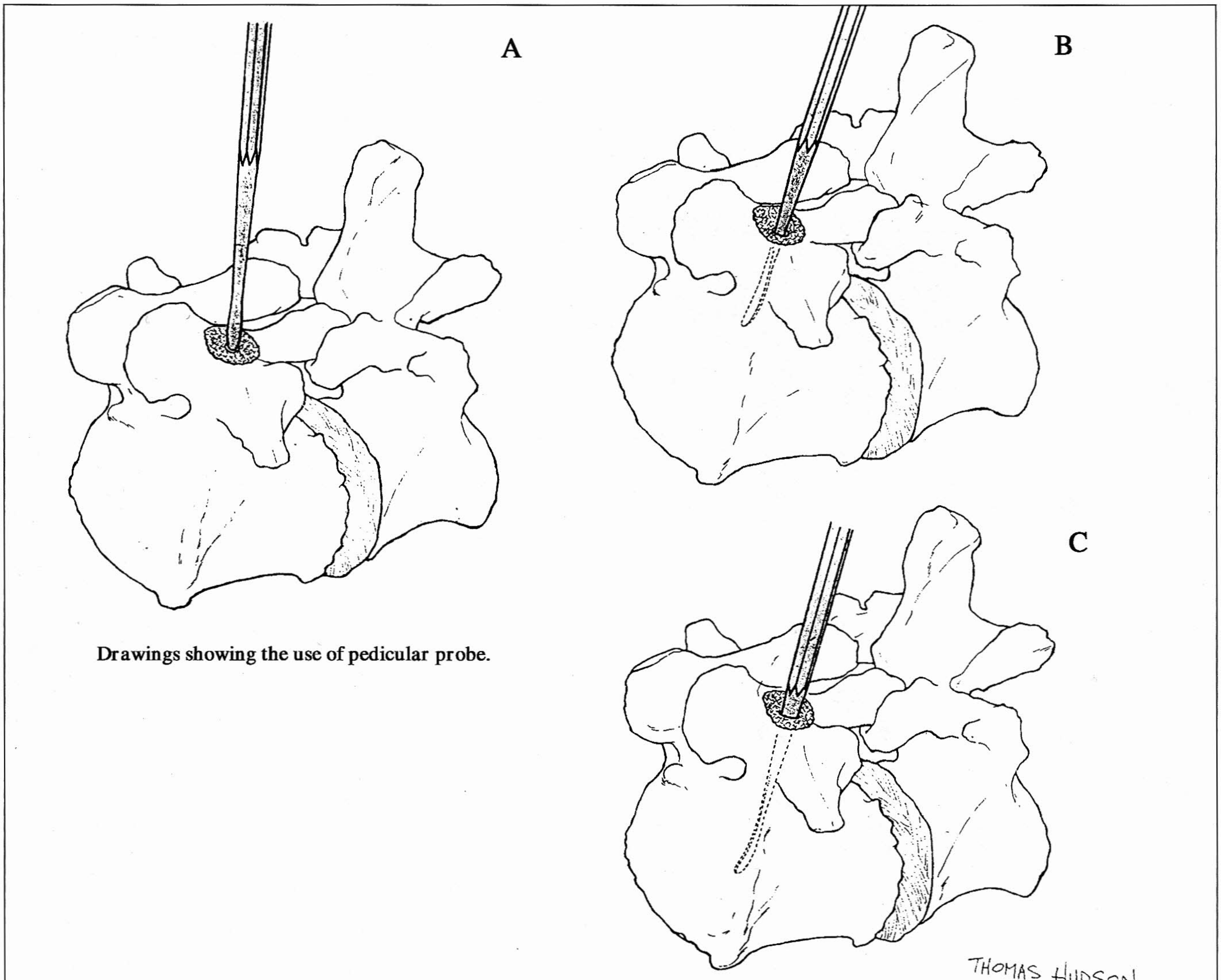

Figure 6. The pedicle probe is introduced into the cancellous bone of the pedicle with a fine twisting motion. Significant resistance may mean the probe is abutting cortex. (Steffee AD: The variable screw placement system with posterior lumbar interbody fusion. In Lumbar Interbody Fusion, Lin and Gill, eds. Aspen, Rockville, 1989, p.85. Reprinted with permission.)

facet, and the transverse process.(Figure 5) Following a midline decompression, the entry point can be verified by visual and tactile inspection of the medial pedicle cortex. During insertion of the most superior screws, great care should be taken to avoid injury to the intact facet at this level and to avoid too medial of an insertion site that would allow impingement of this facet by the instrumentation. A small piece of cortical bone over the entry site is removed with a rongeur and a drill or awl is used to enter the cancellous bone at the most dorsal aspect of the pedicle. The pedicle itself is entered with a pedicle probe, using a fine twisting motion through the cancellous bone. This creates a distinctive "feel".(Figure 6) The usual insertional angles follow an "up and in" position of approximately 15 degrees. By avoiding placing the screws in a "straight in" position, the screw pull-out strength is enhanced and the construct will have better resistance against collapsing into a parallelogram.(Figure7)

The widest screw possible should be used at each pedicle to reduce screw breakage and to increase pull-out strength. Prior to screw placement, the pedicles are tapped, usually to one size smaller than the intended screw width. After tapping and prior to screw placement, the pedicle is carefully probed with a small ball-tipped "feeler" to detect any cortical perforations that may allow nerve root injury by a protruding screw thread. The superior, medial, and inferior walls of the pedicle can also be inspected from the midline decompression. In the lumbar spine, the screws are placed into the vertebral bodies to a depth of 50-80% of the body width. In the sacrum, the screws are most often placed bicortically so that the tip of the screw just perforates the cortex of the sacral promontory in the medial "safe zone", lateral to the middle sacral artery and medial to the internal iliac artery and vein and lumbosacral trunk.[84] (Figure 8) The biomechanical advantage of bicortical over unicortical sacral screws is controversial.[85,86]

Straight and angled washers are routinely used over the screws' integral nuts. This provides more room for lateral bone graft, more evenly distributes the contact pressure between the screws and the longitudinal members, better allows the screws to be placed perpendicularly to the longitudinal member and helps prevent the longitudinal member from impinging upon the superior unfused facet. Autogenous corticocancellous bone graft is placed in each lateral gutter after decortication of the transverse processes, sacral ala and the lateral aspects of each superior facet and pars.(Figure 9) We most often use VSP

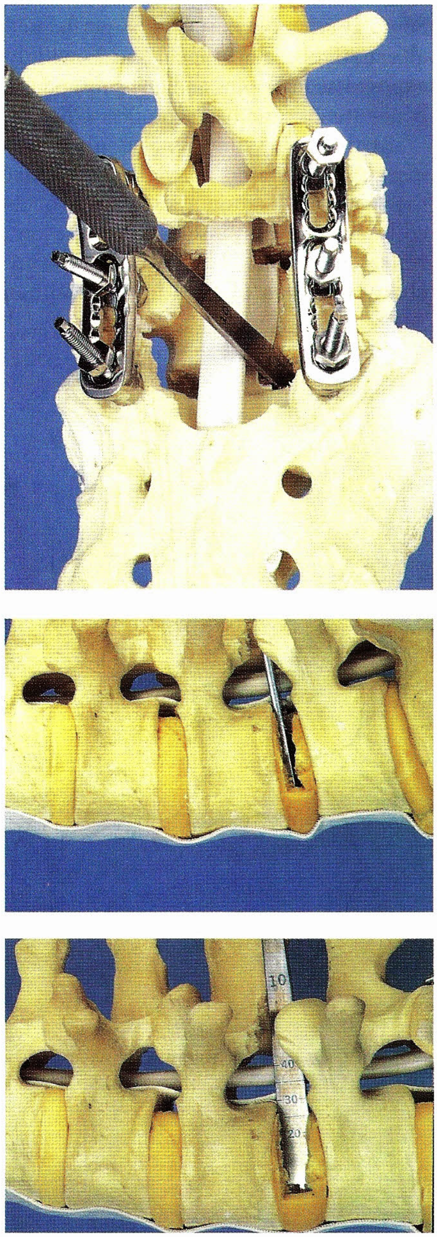

Figure 10a-c. 10a (top): The interbody shaper has been inserted into the disc space and rotated, holding the space in a distracted position. This disc space elevation is maintained by tightening the nesting nuts to the plate. 10b (middle): A cut-away view through the annulus to show how the interbody shaper is inserted parallel to the disc space. 10c (bottom): The 10mm shaper is rotated 90 degrees, thereby distracting the space to 10mm. Shapers of various sizes are available. Note that the instrument is inserted to a maximum safe distance of 30mm.

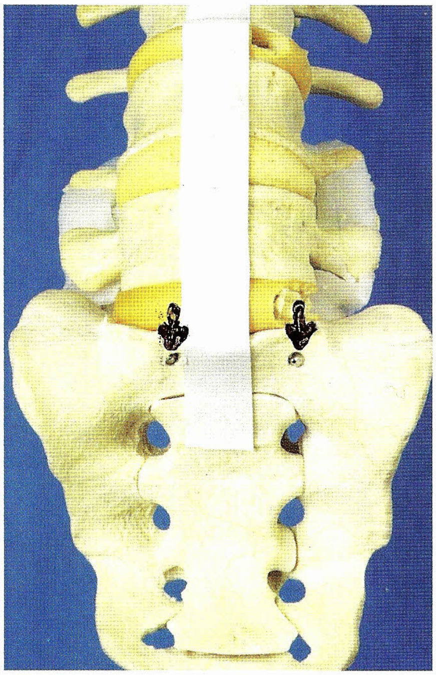

Figure 8. The S1 screws can be placed bicortically so that the tips of the screws just perforate the sacral promontory in the medial safe zone.

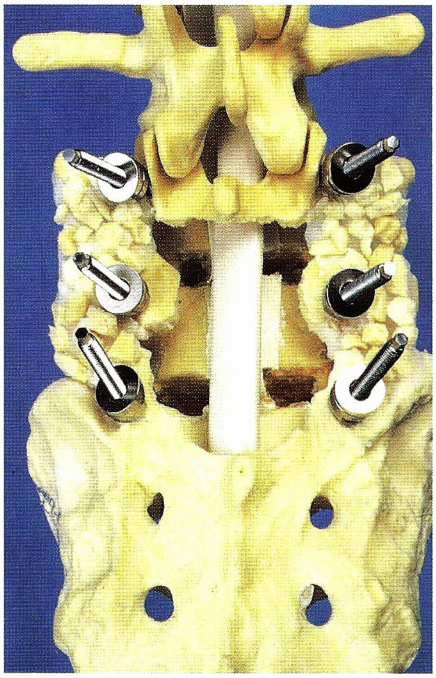

Figure 9. The screws have been placed in an up and in angulation of approximately 15 degrees from the vertical. Note that the superior screws are well away from the unfused L3-L4 facet joints. Posterolateral bone graft has been applied to the decorticated transverse processes, filling the lateral gutters from L4 to the sacral ala. Washers have been placed on the screws. Note the extent of the decompression. The inferior facets of L4 and L5 have been removed, and partial facetectomies of the superior facets of S1 and L5 have been performed. In this specimen, the discs has been already removed.

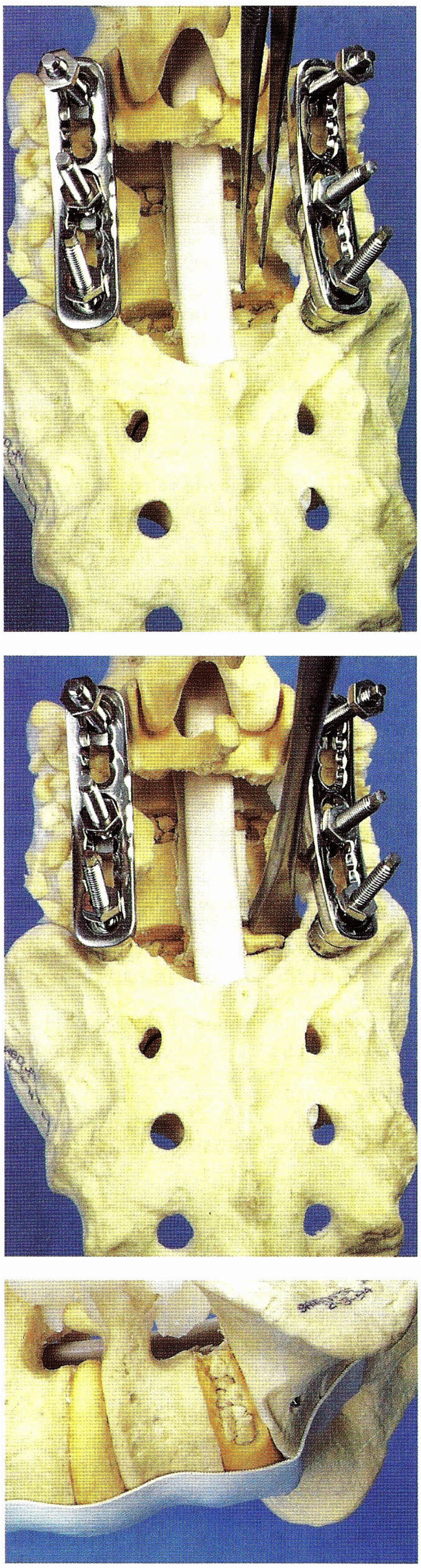

Figure 12a-c. 12a (top): Chips of autologous cortical and cancellous graft from the posterior decompression as well as from the iliac crest are impacted into the disk space. 12b (middle): Larger pieces of cortical bone can be impacted as "caps," locking the chip graft into place. The graft is recessed below the posterior vertebral body line. 12c (bottom): A cut-away view through the annulus to demonstrate how the impacted chip PLIF graft fills the disc space.

plates (Acromed, Cleveland, OH) which are bent into lordosis and applied loosely to the screws. If the screw alignment will not allow easy application of the plates with ginger manipulation, then Isola rods can be substituted.

Once the lateral bone graft has been placed and the plates loosely applied to the screws, attention can be directed to the discectomy and preparation for the interbody grafts. Starting at the most inferior interspace to be fused, the thecal sac is gingerly retracted to the midline and the epidural veins over the disc space are electrocoagulated. The posterior annulus is excised and the disc is entered with a Collis interbody shaper of a size that correlates with the height of the planned disc space elevation. By rotating the shaper 90 degrees, the intervertebral space is widened by this amount.(Figs. 10A-C) The separated vertebral bodies are then locked in this amount of distraction by tightening the nesting nuts to the screws, securing the plates to screws. With the disc space now reelevated, a total discectomy is performed, leaving intact the rim of anterior and lateral annulus. We no longer use pre-cut allograft bone blocks for interbody graft, as originally described,[65] due to concerns of stability, sterility and pseudarthrosis.[87,88] Therefore, we do not use the Acromed broaches. The reamers can be useful in removing disc tissue, a process that is completed with curettes.(Figure 11) Care is taken to decompress any lateral disc protrusion and the vertebral endplate cartilage is removed, leaving the subchondral endplate intact but perforated to expose a bleeding surface. In general, instrumentation should not be inserted greater than 30 mm into the disc space to prevent perforation of the anterior annulus.

Cortical bone from the posterior decompression is meticulously cleaned of soft tissue and divided into small pieces of 5-10 mm. This is mixed with cancellous bone removed from the posterior iliac crest and impacted into the disc space as a chip PLIF graft.[89](Figs. 12A-C) This is repeated on either side of the thecal at each level to be fused. The nesting nuts are then temporarily loosened and the screws are compressed at each segment, re-tightening the nuts while maintaining this segmental compression. This maneuver places the graft under compression and maximizes lordosis. Locking nuts are applied and the plates can then be connected with a transverse loading device to resist lateral displacement in the coronal plane.(Figure 13) The status of the neural decompression and the graft place-

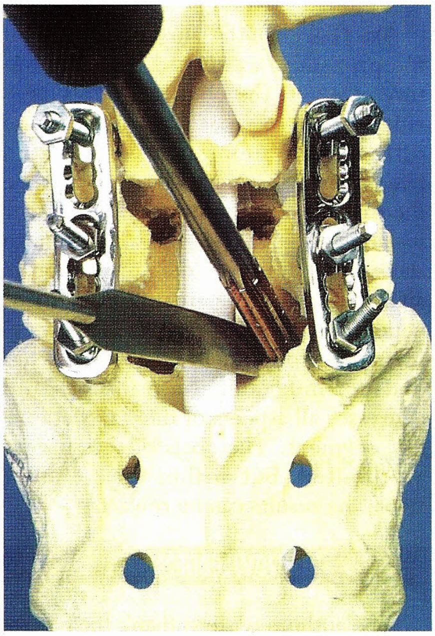

Figure 11. While the retractor is protecting the thecal sac, a reamer of approximate size can be used to debride the disc space. The discectomy is continued with curettes and rongeurs, leaving a bleeding subchonadral boney surface.

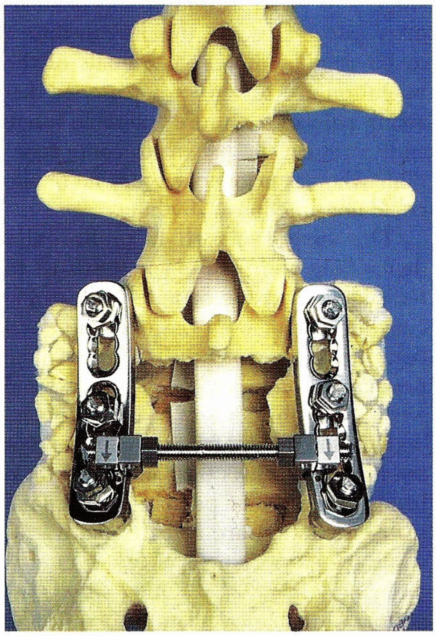

Figure 13. The completed construct. A transverse connector is often used to connect the plates. This is of major importance in a single level construct in which the risk of lateral shifting ("Parallelogramming") would be greater than in multilevel constructs. Note the impacted interbody bone graft, as well as the abundant posterolateral graft beneath the VSP plates. Note that the plates do not impinge upon the unfused L3-L4 facet joints.

ments are reassessed and the machine portion of the screws are cut at their bases. An epidural catheter is placed and drains are inserted. The retracted soft tissue is debrided and lightly closed in the midline to decrease the dead space. The fascia is repaired to the supraspinous ligament where possible.

Patients' lines are removed on the second or third postoperative day and out of bed activities are allowed at that time while wearing a light elastic corset. The average hospital stay is 5 days. Pool therapy is started at 6 weeks post-op and isometric strengthening at 12 weeks. The interbody grafts take approximately 4-6 months to fuse and dynamic muscle strengthening is started at that time. Most patients start back to some work at 3-6 months. Outcome is very dependent on the patient's willingness to follow a carefully designed post-operative spinal rehabilitation program.

RESULTS OF INSTRUMENTED PLIF

An analysis of this procedure's results must consider the procedure's limited goals. Such an extensive spinal reconstruction is a salvage procedure being performed after all other methods have failed to improve a patient's chronic intractable pain. It is not possible for this surgery to make anyone's back "normal" or to assure a patient that he can return to his regular duties. The goals of the operation are to reduce a patient's disabling pain into a more tolerable range and to return the patient to some function, whereas prior to surgery he or she could not function at anything.

The surgery itself is technically demanding and results are sensitive to technique. There is definitely a learning curve in performing the operation and complications can be significant. The procedure combines the risks associated with spinal instrumentation and interbody fusion.[90,91,92] However, we feel that the literature shows that, in experienced hands, the risks of pedicle-based spinal instrumentation are actually quite low, while the enhancement of fusion rates is dramatic.[43,58,59,60,61 64,93] Others have stated that life table calculations predict the survivorship of this instrumentation without complication is 80% at 10 years post-operatively and that this is equivalent to the survivorship of other commonly used orthopedic implants.[94]

It has been said that PLIF is a better method of grafting than posterolateral fusion when performed in conjunction with rigid screw-plate fixation such as the VSP system.[73] Both the percentage of fusions occurring as well as the rate at which they occurred was increased with the PLIF technique. Better correction of spinal deformaties was possible with PLIF, and the screw breakage rate was 1/5 that of instrumented posterolateral fusions. We have already stated that we feel the instrumented PLIF procedure better fulfills the surgical goals when treating degenerative instabilities. Lin reported treating patients with non-radicular LBP with PLIF, obtaining 89% good-excellent results.[95] Collis reported a 96% fusion rate and 100% satisfactory clinical results.[81] Schechter's series reported a 96% fusion rate and 92% satisfactory clinical result following PLIF.[52] A review of our own unpublished data is consistent with the literature. Our results with the "PLIF and plates" procedure for treating discogenic pain showed patient satisfaction (as reported by patient questionnaire) at 87.5%. Clinical success, based upon post-op pain scale, medication use and return to work data, equaled 93.8% in the non-compensation group, versus 87.9% in the compensation group. The nonunion rate was 3%.

SUMMARY

We feel that the surgical results of the procedure as quoted in the literature attest to the clinical efficacy provided by this approach in treating these difficult problems in well selected patients. We have attempted to outline the pathogenesis of degenerative lumbar instabilities. It has been our intention to show that if one considers the option of spinal fusion in the treatment of these conditions, the interbody fusion as performed through a PLIF approach has distinct mechanical advantages and addresses all aspects of the degenerative disc segment. The goals of the surgery are limited, but within these limitations, the results can be rewarding.

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