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Minimally Invasive Surgery of the Spine: Less Is More

Josef E. Gorek, MD,* Kevin W. Rolfe, MD, MPH,† and Cary Idler, MD‡

Minimally invasive surgery of the spine (MISS) has become an increasingly popular buzz word in the spine community. What truly constitutes MISS is not entirely clear. We propose that MISS procedures be judged on the basis of the degree to which they spare additional anatomical structures compared with the existing standard as long as the safety and efficacy of the procedure are preserved. In this work we explore this structure-sparing perspective and the anticipated benefits on patient outcomes, against the notion that small incisions or technology dictate MISS.
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Minimally invasive surgery of the spine (MISS) can be defined as any spinal procedure with acceptable safety and efficacy performed in a manner that minimizes associated iatrogenic tissue damage. The specific procedure that most closely meets that definition will vary with time, surgeon, and most importantly the pathology being treated.

The dictionary definition of minimal in this context refers to the "least necessary." We recommend a preservationist position as minimally invasive techniques relate to spinal surgery. That is to say, it is not a minimal incision, operative time, or blood loss that constitutes MISS, although these may be byproducts; rather, it is doing the least necessary to bring about an optimal outcome with as little iatrogenic disruption to the patient's life and body. The term structure-sparing, or perhaps structure-preserving, is therefore best suited to this discussion.

Inherent in the structure-sparing concept of MISS is the notion that an increasing amount is desirable. We propose an influence on outcomes and complication avoidance as relates to 3 basic periods after surgery (Table 1). First, the initial outcome or recovery phase is the time immediately postoperative up to 6 months. When more structures are spared during surgery, items such as patient recovery time, pain profile, and return to work may improve more rapidly. Second, the primary outcome phase occurs from 6 months to 2 years. To remain viable, a given MISS technique will need to be judged on whether it can provide similarly efficacious outcomes and risk profiles compared with its predecessors. If the recovery phase is improved without an optimal primary outcome, the trade-off is unbefitting. Third, the secondary outcome or maintenance phase is the time beyond 2 years after surgery. In addition to long-term maintenance of the primary outcome, structure-sparing is most often considered in relationship to decreased risk for secondary fusions, transitional syndromes, or adjacent level degeneration. Although clinically unproven at present because of a limited, but growing, body of medical literature, the belief is that increasing amounts of structure preservation through MISS will decrease the rate of secondary fusion or adjacent level degeneration toward the background level because of natural history and aging. MISS therefore targets phases 1 and 3 for improvement over traditional techniques so long as the primary outcome and risk profile in phase 2 remain equivalent or better. If MISS cannot provide an equivalent safe and efficacious primary outcome, then purported benefits within the first and third phases are rendered moot.

Of course, any discussion of what constitutes MISS must take into account the specific pathology being addressed. Clearly, what constitutes minimally invasive treatment of a thoracic compression fracture will be different from the treatment of cervical radiculopathy, or discogenic lumbago. One of the most common pathologies requiring spinal surgery is lumbar disk herniation and perhaps this is therefore an appropriate place to begin the discussion.

*Kaiser Oakland Medical Center, Oakland, CA.
†Department of Orthopedic Surgery, Harbor-UCLA Medical Center, Torrance, CA.
‡Orthopaedic Specialists of North Carolina, Wake Forest, NC.
Dr. Gorek consults for, owns stock in, and sold a patent (2005) to NuVasive Inc. Dr. Idler is a consultant for NuVasive, Inc.
Address reprint requests to Kevin W. Rolfe, MD, MPH, Department of Orthopedic Surgery, Harbor-UCLA Medical Center, 1000 West Carson Street, Torrance, CA 90509. E-mail: kwrolfe@gmail.com

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Table 1 Three Phases of MISS Effect

Phase 1	0-6 months	Recovery
Phase 2	6 months-2 years	Primary outcome
Phase 3	>2 years	Secondary outcome

MISS targets improvement in phase 1 recovery and phase 3 secondary outcomes (eg, risk of adjacent segment breakdown) as long as the primary outcome & risk profile are equivalent or better.

MISS, minimally invasive spinal surgery.

It has been said that the era of minimally invasive spine surgery was ushered in by the clinical efforts of Lyman Smith with the enzyme chymopapain.[1] In 1963, Smith administered percutaneous injections of chymopapain to a patient with sciatica to hydrolyze the mucoprotein of the herniated nucleus pulposis.[1] Thereafter, thousands of patients underwent the treatment of their disk herniation with this injection procedure. Unfortunately, several complications, including intractable back pain, transverse myelitis, and anaphylaxis, were associated with its use. Lower efficacy than that of standard diskectomy and unjustifiably greater complication rates ultimately led to termination of its use in the United States.[1]

Similarly, in part on the basis of efficacy less than that of microsurgical diskectomy,[1] other minimally invasive efforts in the treatment of lumbar disk herniation have not found broader adoption and this is perhaps the reason that some make the claim "minimally invasive surgery is minimally effective surgery." These procedures include percutaneous manual nucleotomy, automated percutaneous lumbar diskectomy, laser diskectomy, and arguably endoscopic diskectomy, given that the early experience with this procedure was associated with greater incidental durotomy rate.[2-4] The more practicable alternative, namely microsurgical diskectomy, performed via subperiosteal dissection and using a small bladed retractor, has a reported success rate of 90% with a complication rate of approximately 2%, including dural tears, nerve root injury, and diskitis.[1] It remains the standard by which other surgical treatments of sciatica secondary to lumbar disk herniation are compared in outcome and risk profile.

One could almost view some of these other procedures, whether based on the use of an enzyme, light energy, or indirect mechanical manipulation, as explorations and deviations from what otherwise was simply a progressive and natural improvement in the standard open and direct mechanical means of decompressing the nerve root by removal of overlying bone, joint, ligament, and underlying disk herniation. In that sense, MISS did not start with chymopapain but rather with the realization that the same or better surgical outcome could be achieved by improving the existing standard via a smaller incision, with less muscle dissection, and/or bone and joint removal. What started as a complete laminectomy and transdural approach to the lumbar disk hernia, evolved into a unilateral laminectomy and extradural approach and ultimately to laminotomy of minimal dimension only so large as to accomplish the necessary effects within the spinal canal.

Similar and parallel advancements can be said to have taken place in the treatment of lumbar stenosis. For instance, a better understanding of the segmental nature of degenerative stenotic pathology as so eloquently and comprehensively discussed in McCulloch's treatise *Essentials of Spinal Microsurgery*[5] has allowed for the use of unilateral laminotomy (rather than bilateral laminectomy) to decompress both sides of the spinal canal while preserving the important dorsal ligaments. The targeted approach to interbody lumbar fusion using intradiscal techniques performed via limited access channels is analogous.

The Evolution of MISS

Indeed, the successful minimally invasive procedures of today are not revolutionary in the sense that they are products of an evolution made possible by the adoption of technologies, such as the microscope, improved lighting, specialized instruments, retractors, fixation systems, and implants. This has allowed a more focused, structure-sparing, and yet still effective treatment of the pathology. Revolutionary change, by contrast, represents true paradigmatic shift. It might be said that the only revolutionary change, and that most profoundly affecting the morbidity associated with spinal surgery, has come with the discovery by Urist of bone morphogenic proteins, thereby changing how bone grafting is performed.[6]

The answer, then, to what constitutes MISS is largely dependent on an analysis of what structures are being spared during the execution of what are otherwise "standard" surgical procedures. The minimally invasive alternatives are still "open" procedures albeit "less open." Perhaps the most instructional and telling analysis comes with a look at modern day minimally invasive lumbar fusion procedures.

The invasiveness of any lumbar fusion procedure can be conceptualized in a stability cascade (Fig. 1). The term "stability" is a surrogate for invasiveness. Structures disrupted can be subcategorized as bridging or nonbridging stabilizers. All additional structures spared via MISS would be expected to improve phase 1 recovery, but assuming segmental fusion is achieved, the structures most important to preserve are bridging stabilizers (static and dynamic). Bridging structures impact the stability of the adjacent segments and when disrupted may lead to a higher likelihood of transition syndrome.

Each fusion procedure can therefore be compared from a structure sparing point of view, say the standard to an MISS version,[7] an example of which is shown in Table 2 for transforaminal lumbar interbody fusion (TLIF). The structures included in Table 2 are those thought to be most important to the discussion in enhancing recovery and reducing the likelihood for negative adjacent segment impact, so-called phase 1 and 3 effects. The open dorsal midline, or "extensile," exposure, although providing a technically straightforward, expeditious and more imaging independent approach to the spine, does so with significant associated morbidity to the dorsal muscles, ligaments, and bony anatomy.

Important muscles include the interspinales, the inter-

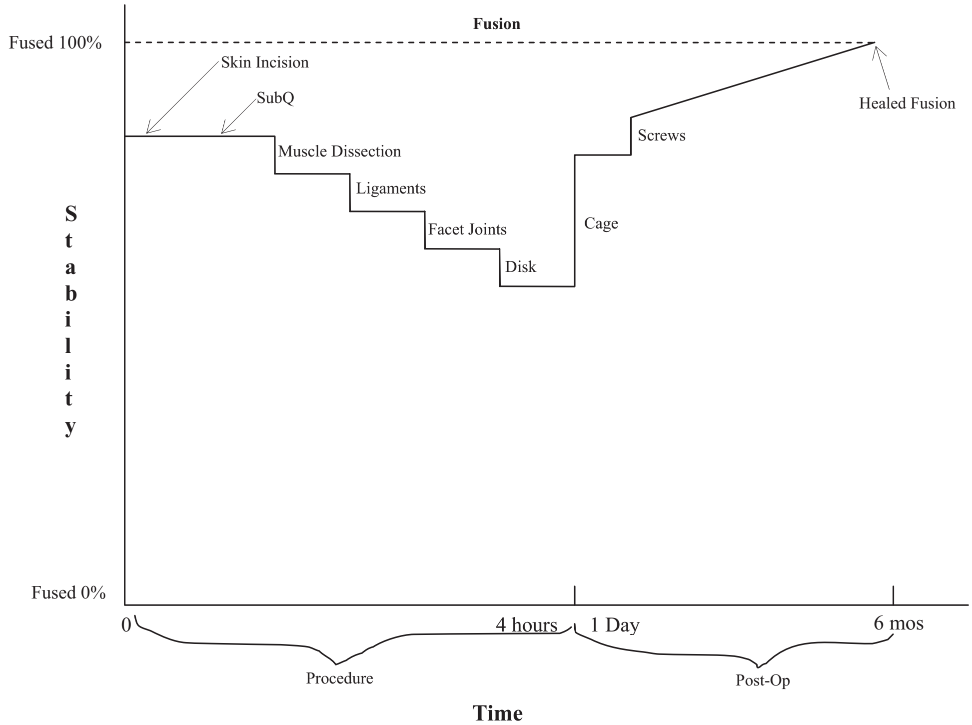

Figure 1 Stability cascade.

transversarii medialies, the multifidus, the lumbar longisimus and the lumbar iliocostalis. The most critical of these, the multifidus, a dynamic segmental stabilizer, is innervated only by the medial branch of the dorsal ramus and is without intersegmental innervation as is true for the other paraspinal muscles. The innervation and blood supply course in a ventrolateral to dorsomedial direction in close proximity to the mamillary process.[8] Damage to the muscle can occur from denervation, devascularization, detachment and prolonged compression during retraction.

Important ligamentous structures include the supraspinous and interspinous complex, intersegment stabilizers during flexion. In extension, the primary resistance comes from the facet joints, the anterior longitudinal ligament, and possibly the spinous processes. Segmental control during flexion and resistance to instability involves a synergy of the supraspinous/interspinous ligament complex, multifidus muscles (to a lesser degree, iliocostalis, longissimus and spinalis muscles), ligamentum flavum, facet capsule, posterior longitudinal ligament, and disk. Among these, the supraspinous/interspinous ligament complex, multifidus muscles, and adjacent facet capsule are bridging structures to the adjacent level that may be spared while fusing a segment. In a porcine model, Gillespie et al[9] showed that the supraspinous/interspinous ligament complex alone was the largest contributor to flexion resistance (35.9%), followed by the disk

Table 2 Standard TLIF vs MISS TLIF Structure-Sparing Analysis

	Skin	Subcutaneous Tissue	Dorsal Facia	Supraspinous / interspinous Ligament Complex[a]†	Mucsle Attachments[b]†	Bilateral Muscle attachments[b]†	Facet Capsule[c]†	Dorsal Rami (neurovascular bundle) at the Pars Interarticularis	Ligamentum Flavum	Lamina	Partial facet joint resection	Total facetectomy	Posterior Longitudinal Ligament Resection	Posterior Annulus	Nucleus Pulposis	Anterior Longitudinal Ligament	Psoas	Prerectus fascia	Rectus Abdominus	Oblique Muscles[d]		
Open TLIF w/ Post/Lat Fusion	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*							
MIS TLIF with B/L Percutaneus	*	*	*						*	*		*	*	*	*							

[a] Includes supraspinous, interspinous ligaments and spinous process (SP).
[b] Includes multifidus, spinalis, some longissimus, as well as adjacent-level attachments to SP, lamina and transverse process (TP).
[c] Includes facet capsule, nerve & blood supply to facet capsule as well as possible injury to adjacent level facet.
[d] Internal, external, and transversus abdominus.
* Denotes structure injured, cut, or otherwise compromised during the approach.
† Denotes bridging structures to adjacent level.
MIS, minimally invasive surgery; TLIF, transforaminal lumbar interbody fusion.

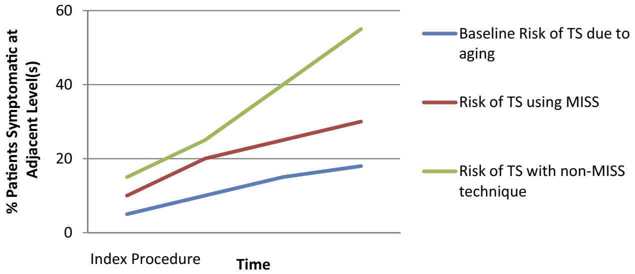

Figure 2 Theoretic relative differential risk of transitional syndrome. (Color version of figure is available online.)

(25.2%), and ligamentum flavum (24.7%). Moreover, in 1980 Adams et al[10] showed in a human cadaveric model that resistance to a flexion moment occurred first through the supraspinous/interspinous ligament complex and then, subsequently, by facet capsule and disk. Of course, for the segment being fused these may be sacrificed in the name of treatment, but need not be sacrificed across the unfused segments. Across unfused segments, Chen et al,[11] also by using a porcine model, demonstrated no difference in adjacent level flexion mobility between control and laminotomy where the supraspinous and interspinous ligaments remained intact compared with laminectomy which was inferior to preservation of flexion stability, though comparable for extension.

We believe, therefore, a strong argument can and should be made to try to spare especially those structures that bridge to the adjacent level of a fusion; namely the supraspinous/interspinous ligament complex, adjacent facet capsule, multifidus muscles, and to a lesser extent, the spinalis, longissimus and iliocostalis muscles. These are the structures that both affect adjacent level stability and may be spared with "minimally invasive" approaches to posterior lumbar surgery (Fig. 2).

In attempt to preserve these important dorsal anatomic structures, different surgical procedures have been developed, including posterior MISS variations and posterior alternatives such as anterior lumbar, transpsoas, and transosseous interbody approaches where the morbidity to the dorsal muscles might be avoided entirely (Table 3). The anterior lumbar approach can be done via a midline incision without damage to rectus abdominus muscles (the rectus is displaced laterally toward its neurovascular pedicle) and has the associated advantage of affording access to the lower 4 disk spaces (although achieving access to L2-L3 may be challenging), or through an anterolateral incision during which the layered abdominal wall muscles are split in line with their fibers. No muscle need be cut or released from the spine. Transpsoas procedures similarly traverse the layered abdominal wall muscles via a direct lateral incision but do require additional dilation of the psoas muscle to gain access to the lateral aspect of the disk. Transient hip flexor weakness is not uncommon as a result.[12] The L5-S1 disk is not accessible using this approach. The transosseous approach (or transsacral approach to L5-S1) uses a paracoccygeal incision that requires no muscle dissection. If posterior surgery is elected, strategic placement of the skin incisions allowing for "muscle splitting" type dissection between the muscle fascicles, perhaps in combination with specialized retraction devices and percutaneous, fluoroscopically guided pedicle screw techniques, help to minimize exposure related muscle damage. Indeed, changing from open to percutaneous pedicle screw technique may be the single most important alteration in technique that most reduces the morbidity associated with posterior instrumented procedures. This can be done with accuracy that exceeds that of open screw placement.[13]

More important than the length of the skin incision to the minimization of morbidity of dorsal procedures is the planning and placement of the incision such that it facilitates optimal trajectory through the more superficial tissues toward the targeted structures. This concept can be dated back to Wiltze in 1988 and most directly relates to the minimally invasive TLIF for which the incision is usually made about 4 to 5 cm off the midline.[7] Although traversing muscle via the "natural cleavage plane between muscle fascicles" as described by Foley et al,[7] the approach is, however, not entirely without morbidity to the muscle. Indeed, to gain access to the facet joint, the multifidus insertion on the mamillary process and facet joint capsule that lies next to it must be released. The important medial branch of the dorsal ramus invariably is cauterized during the clearing of soft tissue from the surgical field which leads to the denervation of the more medial multifidus fibers. Furthermore, dorsal and medial mobilization of the muscle away from its neurovascular pedicle as encountered during those muscle-splitting TLIF procedures that require access to the more medial spinolaminar junction, ie, for decompression of the contralateral aspect of the spinal canal, may also result in denervation if the nerve has not already been transected. This nuanced analysis points to a possible advantage of the minimally invasive posterior lumbar interbody fusion (PLIF) procedure, which uses a path through the muscle that is more medial and initiated through skin incisions only 2.5 cm off the midline.[14] It is conceivable that less muscle is released, denervated, and devascularized, although the procedure is usually undertaken bilaterally, diminishing its relative potential benefit. Also, a relative disadvantage of the minimally invasive PLIF compared with the TLIF is the additional neural element manipulation required to perform the disk space preparation and interbody cage and graft placement. Recent work by Fan et al[15] supports the contention that less muscle damage is incurred when these minimally invasive techniques are used. A comparison was made between minimally invasive posterior lumbar interbody fusion versus the conventional open approach and muscle damage assessed by magnetic resonance imaging and creatinine kinase levels. They concluded that muscle atrophy was less in the minimally invasive group. To our knowledge, analysis of muscle damage associated with one minimally invasive technique compared with others has not been done.

Ultimately, the "ecomony of exposure" of these fusion procedures is largely founded on the fact that canal access needed to accomplish the decompression is the same as that needed for preparation of the spinal segment for successful fusion. This is possible because of the segmental nature of

Table 3 Structure-Sparing Analysis of Different Techniques Used for Interbody Fusion

	Skin	Subcutaneous Tissue	Dorsal Facia	Supraspinous / interspinous Ligament Complex[a]‡	Muscle Attachments[b]‡	Bilateral Muscle attachments‡	Facet Capsule[c]‡	Dorsal Rami (neurovascular bundle) at the Pars Interarticularis	Ligamentum Flavum	Lamina	Partial facet joint resection	Total facetectomy	Posterior Longitudinal Ligament Resection	Posterior Annulus	Nucleus Pulposis	Anterior Longitudinal Ligament	Psoas	Prerectus fascia	Rectus Abdominus	Oblique Muscles[d]
Open TLIF w/ post/lat fusion and total laminectomy	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
MIS TLIF with B/L percutaneus instrumentation	*	*	*						*	*		*	*	*	*					
Lateral interbody fusion	*	*													*		†			†
Anterior Interbody fusion	*	*												*	*	*		*		
Trans-sacral fusion (L5-S1 only)	*	*													*					

[a] Includes supraspinous, interspinous ligaments and spinous process (SP).
[b] Includes multifidus, spinalis, some longissimus, as well as adjacent-level attachments to SP, lamina and transverse process (TP).
[c] Includes facet capsule, nerve & blood supply to facet capsule as well as possible injury to adjacent level facet.
[d] Internal, external, and transversus abdominus.
* Denotes structure injured, cut, or otherwise compromised during the approach.
† Denotes possible or partial structure injured, cut, or otherwise compromised during the approch.
‡ Denotes bridging structures to adjacent level.
MIS, minimally invasive surgery; TLIF, transforaminal lumbar interbody fusion.

stenotic pathology. If the compressive pathology is not focal to the disk space level, this is less true, ie, for an extruded or sequestered disk fragment at distance from the disk of origin. Indeed, all minimally invasive lumbar fusion procedures, save for minimally invasive posterior lumbar fusion, have in common the fact they involve interbody fusion which not only minimizes morbidity, but also enhances efficacy. This approach to lumbar fusion can be dated back to Mercer's conclusion in 1936 that the ideal lumbar fusion operation would be an interbody arthrodesis.

It has long been recognized that high fusion rates can be achieved via a variety of approaches that afford access to the disk space especially when these interbody techniques are augmented with pedicle screws. TLIF and PLIF accomplish the disk space preparation and grafting via complete or partial facet joint resection, which is the same portal into the spinal canal used for decompression. The muscle dissection therefore needed to accomplish one goal is the same as for the other. For those anterior lumbar procedures in which direct decompression of the spinal canal is possible, ie, for disk hernia as the primary compressive pathology, this is also the case. This is akin to anterior cervical decompression and fusion and can be labeled ALDF or anterior lumbar decompression and fusion.

When direct decompression is not possible through the same portal as that used for preparing the fusion bed, indirect decompression of neural elements can at times be afforded by reestablishing disk space height and restoration of normal segmental alignment using any of the intradiscal fusion techniques, including transpsoas or transosseous. Maintenance of alignment and hence the decompression is facilitated by intradiscal cages or structural allograft and secondary instrumentation as needed. Data supporting the contention that indirect decompression of neural elements can be effective is found in Carragee's work on L5-S1 fusion for spondylolytic spondylolisthesis, and Zucherman's work on indirect decompression of lumbar stenosis using interspinous distraction devices.[16,17] Additional data related to the efficacy of these techniques is now becoming available and has been reported at IMAST (2010).[18]

Discussion

Although it might be reasonable to argue that it is still too soon to make a sound assessment of what is today called minimally invasive lumbar fusion, objective support for the safety and effectiveness of some of these procedures is now becoming available. In 2002, Khoo et al,[14] in detailing a then novel minimally invasive PLIF procedure developed in an effort to minimize what the authors thought to be "unnecessary trauma to the lumbar musculoligamentous complex," concluded that "prospective, randomized studies will be required to validate the efficacy of this exciting new surgical technique." Foley et al[7] in 2003 provided an overview of the then available minimally invasive fusion techniques, including minimally invasive anterior lumbar interbody fusion

(ALIF), laparoscopic transperitoneal ALIF, mini-open retroperitoneal ALIF, endoscopic retroperitoneal lumbar fusion, minimally invasive PLIF, minimally invasive TLIF, minimally invasive posterolateral lumbar fusion, and percutaneous spinal fixation. The authors did not address transpsoas fusion procedures, which were granted a rebirth and have since gained popularity. Setting aside laparoscopic ALIF, they concluded that "although minimally invasive spinal techniques have a logical basis and are appealing to patient and surgeon alike, only prospectively conducted, long-term studies will clearly determine their advantages and disadvantages as compared with conventional open surgeries."[7,14]

We are now in 2010. Rampersaud et al performed a systematic review of the literature to identify reports comparing MISS posterior arthrodesis with open procedures for lumbar degenerative disease; the results were reported at IMAST (2010).[18] Eight articles were identified that met their inclusion criteria. Two of 5 studies with clinical outcomes reported significantly better outcomes in those patients having undergone minimally invasive surgery compared with control patients at early (1 day to 6 weeks) and later (12 month) follow-up. Three articles reported no significant difference in clinical outcome ranging from 6 month to 2 years' follow-up. Overall, MISS patients had fewer complications with apparently equivalent fusion rates. Lee et al[19] in a 2010 evidence-based reviewed of the literature relating to minimally invasive spine surgery dedicated a subsection of their review specifically to lumbar fusion techniques. Their generalized conclusion regarding minimally invasive spine surgery was that it had proven to be a "safe and effective alternative to the traditional open approaches, allowing patients to recover faster with less postoperative pain."

Notably, longer-term outcomes, ie, in the 5- to 10-year range that might also reflect differences between the minimally invasive and standard open procedures in regard to juxtafusional degeneration ("transition syndrome") are not yet available. We would venture that those fusion procedures which maintain the greatest degree of integrity of the dynamic and static stabilizers of the adjacent segments will least likely lead to such degeneration, but concede that "prospective, randomized studies will be required to validate" this contention.

Conclusions

Dr Fessler,[20] in his foreword to the Neurosurgery Supplement on Minimally invasive Spine Surgery in 2002, suggested that "we may be in the early phase of a concept shift" in how spine surgery is going to be performed. In lumbar fusion surgery, the minimally invasive techniques that have taken hold are really evolutionary improvements on accepted procedures. These newer procedures respect the importance of maintaining the integrity of dynamic and static stabilizers of the spine while effectively treating the pathology at issue. Outcome studies now becoming available demonstrate that patients treated using these techniques can have less postoperative pain, shorter hospital stays and can return to function sooner while achieving longer-term outcomes equal to or better than associated with conventional open surgery.[18] Although small skin incisions may be more appealing to the patient, they are not a necessary component of "structure sparing surgery." Indeed, those surgeons reluctant to make a change in their technique because of the additional challenges imposed by the constraints of small incision surgery should consider performing "minimally invasive" techniques via incisions sufficient in size to facilitate a more practicable surgery. Our assumption is that most of the benefits attributed to minimally invasive fusion techniques could still be realized.

It is our view that whether a spinal surgery constitutes minimally invasive surgery should be determined not by what technology is used in carrying out the procedure or by the length of the skin incision used, but rather by a fundamental structural analysis and comparison of tissues disrupted vs. tissues spared. Although we have chosen to focus much of this effort on lumbar fusion, the concept of applying such a structural analysis to any surgery is the point to be made, so long as it is considered within the constraints of prerequisite safety and efficacy.

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