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# Use of Minimally Invasive Surgical Techniques in the Management of Thoracolumbar Trauma

## Current Concepts

Y. Raja Rampersaud, MD,* Neel Annand, MD,† and Mark B. Dekutoski, MD‡

**Study Design.** Literature review and expert opinion.

**Objective.** To provide an overview of the current concepts of minimally invasive surgical (MIS) techniques for the management of thoracolumbar (TL) spinal trauma.

**Summary of Background Data.** Current surgical treatment of thoracolumbar trauma typically involves open placement of spinal instrumentation with fusion. Conventional open spinal exposures can be associated with significant muscle morbidity that can lead to subsequent paraspinal muscular atrophy, scarring, decreased extensor strength and endurance, as well as pain. This approach-related morbidity is the main impetus for application MIS techniques to spinal procedures including trauma.

**Methods.** A review of the relevant English literature was performed.

**Results.** The current rationale, clinical applications, outcomes, and limitation of MIS management of TL injuries are summarized.

**Conclusion.** The application of MIS techniques to spinal trauma is theoretically sound. However, the indications and technology are currently in evolution. Although very limited information is available, the results of current MIS techniques for the management of TL trauma are encouraging.

**Key words:** spine trauma, thoracolumbar, minimally invasive, instrumentation. **Spine 2006;31:S96–S102**

Over 150,000 North Americans sustain a traumatic injury to the vertebral column each year.[1] These injuries can result in potentially devastating sequelae including paralysis, pain, deformity, and loss of function.[2–5] In addition to the physical consequences, the long-term effects of spinal injuries may also have a significant psychologic, economic, and social impact.[6–9]

The overall management principles for treating spinal injuries focuses on maximizing clinical outcome by obtaining and maintaining spinal stability and optimizing neurologic function. An optimal treatment method should have the potential to safely reduce the detrimental effects of injury, reduce pain and suffering, and improve functional outcome and quality of life. In addition, this treatment should provide the best outcome with the least amount of associated morbidity.

The objective of this review article is to provide the current concepts behind the rationale, clinical application, outcomes, and limitations for the use of minimally or less invasive surgical techniques (MIS) in the management of thoracolumbar (TL) spinal trauma management.

### *Rationale*

In the current surgical armamentarium, there are no standard surgical approaches or interventions for spine fracture management. Current surgical treatment typically involves conventional open exposures and placement of spinal instrumentation with fusion. In the trauma population, these conventional techniques can be associated with significant morbidity due to increased infection rates and high blood loss.[2,10,11] In a recent systematic review of the surgical management of TL trauma, Verlaan *et al*[11] reported median blood loss greater than 1,000 mL for posterior, anterior, or anterior-posterior procedures. The average infection rates reported from the 138 papers reviewed was 0.7% for anterior procedures to 3.1% for posterior procedures. As reported by Rechtine *et al*, an infection rate as high as 10% can occur in this patient population.[10]

In addition, conventional open procedures can also be associated with significant approach-related morbidity. Anterior transthoracic or transdiaphragmatic approaches can be associated with significant perioperative pain, shoulder girdle dysfunction, and difficulties with ventilation.[12–14] Standard midline posterior spinal approaches have also been shown to cause significant muscle morbidity resulting from iatrogenic muscle denervation (particularly with exposure lateral to the facet), increased intramuscular pressures, ischemia, and revascularization injury.[15–19] All of these effects can lead to paraspinal muscular atrophy, scarring, and decreased extensor strength and endurance.[20–25] Denervation and ischemia can result from two possible mechanisms that can occur independently or in combination: 1) direct trauma to the dorsal roots and vasculature can occur; and 2) increased intramuscular pressure (*i.e.*, focal compartment syndrome) resulting from commonly used surgical retractors.[18] This phenomenon may result in irreversible electrophysiologic and histiologic changes in the paraspinal musculature as reported in human and animal studies.[15–17,21] The clinical effect of this muscle morbidity can be a significant source of postoperative pain and

From the *Toronto Western Hospital, University of Toronto, Toronto, Ontario, Canada; †Cedars-Sinai, Los Angeles, CA; and ‡Mayo Clinic, Rochester, MN.

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Address correspondence and reprint requests to Y. Raja Rampersaud, MD, FRCSC, Toronto Western Hospital, University Health Network, East Wing 1-441, 399 Bathurst St., Toronto, Ontario, Canada, M5T-2S8. E-mail: raja.rampersaud@uhn.on.ca

functional impairment in the convalescent period as well as long-term. This effect has not been specifically studied in the trauma patient; however, it may be worse in trauma cases where there is already significant paraspinal soft tissue injury (including muscular).

As a result of the aforementioned clinical effects of conventional posterior spinal exposure, minimally invasive or minimal access posterior procedures for the treatment of degenerative spinal disorders has gained momentum over the last 10 years.[26–36] The immediate clinical outcomes regarding amelioration of preoperative symptoms appear to be at least equivalent, if not favorable, when compared with open procedures. Postoperative recovery time, pain, and time to return to work appear to be reduced for these MIS techniques, but this claim has yet to be supported in any well-controlled prospective studies.

Consequently, the rationale for applying minimally invasive techniques in the management of thoracolumbar trauma is to reduce the approach-related morbidity associated with conventional techniques. In the spine, the best possible example of the potential impact that MIS techniques may have is for percutaneous augmentation of vertebral osteoporotic fractures by vertebroplasty and more recently kyphoplasty.[37–41] The focus of this paper is MIS applications to the management of nonosteoporotic TL trauma. The reader is referred to the large body of literature on vertebroplasty and kyphoplasty.

#### Requirements for Applying MIS Techniques to TL Trauma

MIS techniques require an extensive knowledge of the focal anatomy (structural and radiographic) of interest and the surrounding nonvisualized spinal and related structures. Furthermore, the ability to work through narrow channels and perform the procedure safely is highly dependent on adequate visualization (direct and radiographic) of the area(s) of interest as well as having the appropriate equipment to achieve the technical goals of the procedure.

For anterior procedures, endoscopic approaches have been the mainstay of MIS approaches. The appropriate training and experience of operating with an endoscope (thoracoscopic and laparoscopic) are paramount considerations. The majority of TL trauma occurs at the thoracolumbar junction; thus, knowledge and experience with techniques of dealing with the diaphragm are required. Appropriate general and spine specific endoscopic instruments to perform discectomies and corpectomy are required. Also, endoscopic specific or adaptable spinal implants are required.

MIS posterior fixation necessitates the percutaneous delivery of pedicle screws and rods. Several percutaneous posterior instrumentation systems are available on the market. Currently, none is specifically designed for trauma. Most screw systems are cannulated to allow percutaneous placement. Delivery of the connecting rod differs between different manufacturers. A thorough knowledge of the strengths and weaknesses of the instrumentation system will help minimize potential complications.

**Table 1. Current MIS Techniques Used in TL Trauma**

| MIS Technique(s) | Indications |
|---|---|
| Anterior endoscopic decompression and stabilization | Anterior decompression<br>Anterior column reconstruction |
| Posterior percutaneous segmental pedicle screw fixation | Restoration of posterior tension band<br>Indirect augmentation of anterior column<br>Augmentation of anterior fixation<br>Substitution for when direct anterior fixation is not feasible |
| Percutaneous vertebral body balloon-assisted endplate reduction and augmentation | Endplate reduction and vertebral height restoration<br>Augmentation of anterior column |
| Temporary percutaneous posterior fixation | Temporary stabilization to facilitate mobilization or prevention of secondary injury in an unstable injury when definitive fixation is unsafe |
| Combinations of the above | |

The use of intraoperative imaging is necessary with MIS techniques. Biplanar fluoroscopy is preferable. A three-dimensional mobile C-arm is useful for intraoperative confirmation of instrumentation placement. Computer-assisted navigation systems may be used as an adjunct for localization and reduction of radiation exposure. MIS techniques often require a substantial amount of fluoroscopy; consequently, appropriate education and techniques to reduce patient and occupational radiation exposure are prudent.[42–45] The use of neurophysiologic monitoring can also be a useful safety adjunct.

#### Current Techniques

Currently, the application of minimal access techniques to spinal trauma follows four basic concepts that have been applied in isolation or combination (Tables 1, 2): anterior endoscopic decompression and stabilization, posterior percutaneous tension band restoration or augmentation, percutaneous vertebral body balloon-assisted endplate reduction and augmentation, and temporary percutaneous posterior fixation.

#### Anterior Endoscopic Decompression and Stabilization

Anterior endoscopic decompression and stabilization techniques have been used as a stand-alone procedure alone or with supplemental posterior tension fixation for "burst" type TL fractures.[26,46–50] This technique has been successfully used in several European and a few select North American centers. However, because of a variety of technical challenges, initial increased operative time, limited instrumentation, and experience with endoscopic techniques for trauma, the endoscopic techniques have not gained significant popularity in North America.[47]

Khoo *et al* published a consecutive series of 371 patients who had thoracoscopic-assisted treatment of TL fractures performed in Germany.[46] In 35% of patients, a stand-alone anterior thoracoscopic reconstruction was

**Table 2. Thoracolumbar Injury Types Where the Application of Minimally Invasive Spinal Techniques Can Be Considered and Applied**

| Injury | Options for MIS Application(s) and Clinical Indications |
|---|---|
| Axial loading (compression/ burst fractures) | Primary endoscopic/minimal access anterior decompression and fixation<br>Neurologically impaired patient requiring decompression<br>Burst fracture with insufficient anterior column support not amenable to nonoperative or where short-segment posterior fixation is likely to fail<br>Supplemental percutaneous posterior fixation in combination with an anterior procedure (formal open, mini-open, endoscopic, or percutaneous balloon-assisted)<br>Anterior fixation is not feasible or inadequate (*e.g.*, osteoporosis)<br>Anterior column support is inadequate (*e.g.*, osteoporosis, early evidence of anterior graft pistoning)<br>Primary percutaneous posterior fixation* with MIS posterior decompression<br>Patients with radiculopathy amenable to focal decompression using a limited muscle-splitting approach (*e.g.*, tubular retractor)<br>Primary percutaneous posterior fixation* with fusion (with or without limited decompression)<br>Neurologically intact (or with radiculopathy) unstable burst (*i.e.*, disruption of the posterior bony or ligamentous complex)<br>Note: MIS posterior fusion when indicated can be accomplished using a limited muscle slitting approach. Direct decortication of the facets (and or the posterolateral spine) and packing with bone graft or a clinically proven substitute can be accomplished with a small tubular retractor (18 mm). |
| Flexion-distraction | Primary percutaneous posterior fixation* without fusion<br>Pure osseous injury<br>Note: percutaneous instrumentation can be placed selectively across motion segments that are not injured to enable fixation. The instrumentation is then removed once the primary injury is healed (>6 mo).<br>Primary percutaneous posterior fixation* with fusion (see above)<br>Combined or pure disco-ligamentous injury |
| Fracture-dislocation | Temporary percutaneous posterior fixation* without fusion<br>Polytrauma scenario where definitive spinal fixation is medically unsafe<br>Note: definitive stabilization can be conducted at a later interval without compromise |
| Stable injuries (*i.e.*, compression/burst fractures) where use of an orthosis is contraindicated | Primary percutaneous posterior fixation* without fusion<br>Patients with significant chest or abdominal trauma, rib fractures, pelvis fractures, or morbid obesity |

The indications for and application of minimally invasive surgical techniques are in a current state of discovery and evolution.
*This technique is also facilitated by postural reduction.

performed using the MACS-TL system (Aesculap, Tuttlingen, Germany). A steep learning curve was noted, with an average operating time of 300 minutes in the first 50% of cases and an average of 180 minutes thereafter. The rate of severe complications rate was low (1.3%), with 1 case each of aortic injury, splenic contusion, neurologic deterioration, cerebrospinal fluid leak, and severe wound infection. Others have reported on a similar technique with favorable results.[47–49] Verheyden *et al* reported on a novel hybrid mini-open approach for anterior column reconstruction in 42 patients with 59 TL injures from T4 to L4.[50] These procedures were all performed with the patient in the prone position using a 4- to 5-cm incision combined with endoscopic and fluoroscopic assistance. A simultaneous anterior-posterior (conventional posterior approach and instrumentation) was performed in 20 patients. This technique was time neutral for the anterior alone procedures and time saving (average of 40 minutes) for the simultaneous procedures. The authors reported no intraoperative complications; however, no follow-up information is provided. As noted by the authors, this technique may be ideally suited to avoid some of the technical challenges associated with a pure anterior endoscopic approach and can be combined with percutaneous posterior instrumentation techniques.

Compared to conventional open techniques, reduced blood loss, perioperative pain, reduced time to mobilization, and hospital stay have been noted.[46–51] However, no differences in long-term outcomes have been shown in these limited case series. Furthermore, there is no Level 1 or 2 evidence showing superiority or inferiority of these MIS techniques compared with conventional techniques.

### *Posterior Percutaneous Tension Band Restoration or Augmentation*

The use of percutaneous posterior pedicle screw rod fixation techniques can be used as a stand-alone fixation for stable burst or flexion distraction injuries (Figure 1) with or without fusion (late removal of the implants may be required when stabilization is carried out across motion segments which have not been fused); augmentation (Figure 2) of formal or minimally invasive anterior decompression with or without instrumentation (this can be primarily or secondarily depending on the comorbidities of the patient); or in conjunction with minimal access posterior decompression and fusion approaches.

Assaker has reported on the application of this technique as both a primary stand-alone technique or in combination with an anterior endoscopic approach.[26,51] At the 2005 Eurospine Meeting, Assaker presented a 6- to 28-month follow-up (mean, 12 months) on 40 neurologically intact patients stabilized with primary posterior percutaneous fixation for single level burst type or flexion distraction (AO Types A2, A3, and B1) fractures. The average operative time was 75 minutes with trivial blood loss and no infections. The average loss of correction was 7.5°. Good to excellent outcomes were achieved

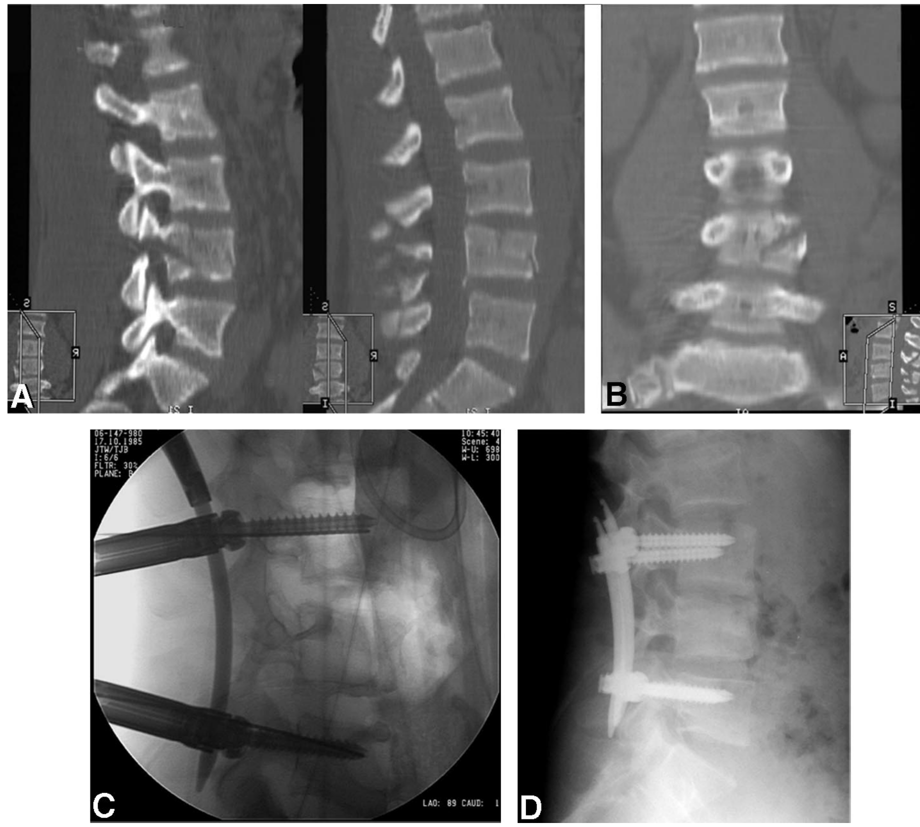


Figure 1. **A**, Preoperative sagittal computed tomography (CT) reconstruction demonstrating a predominantly bony flexion-distraction injury at L4. **B,** Preoperative coronal CT reconstruction demonstrating the fracture extending up through the pedicle. **C,** Intraoperative image demonstrating percutaneous placement of intervening 5.5-mm rod. **D,** Upright postoperative lateral radiograph demonstrating reduction and stabilization of the distractive flexion injury.

in 87.5% of patients (Prolo score). Three patients required revision surgery: 2 at 1 year for persistent back pain and 1 acutely for a medially (6 mm) misplaced pedicle screw (no neurologic symptoms). Dekutoski (unpublished observation) has reviewed 16 TL trauma cases (n = 10 polytrauma patients) with 12 to 24 months of follow-up. Percutaneous posterior fixation was used as the primary means of fixation in 11 cases and as supplemental fixation to anterior corpectomy, instrumentation, and fusion in 5. In 4 patients without fusion, the

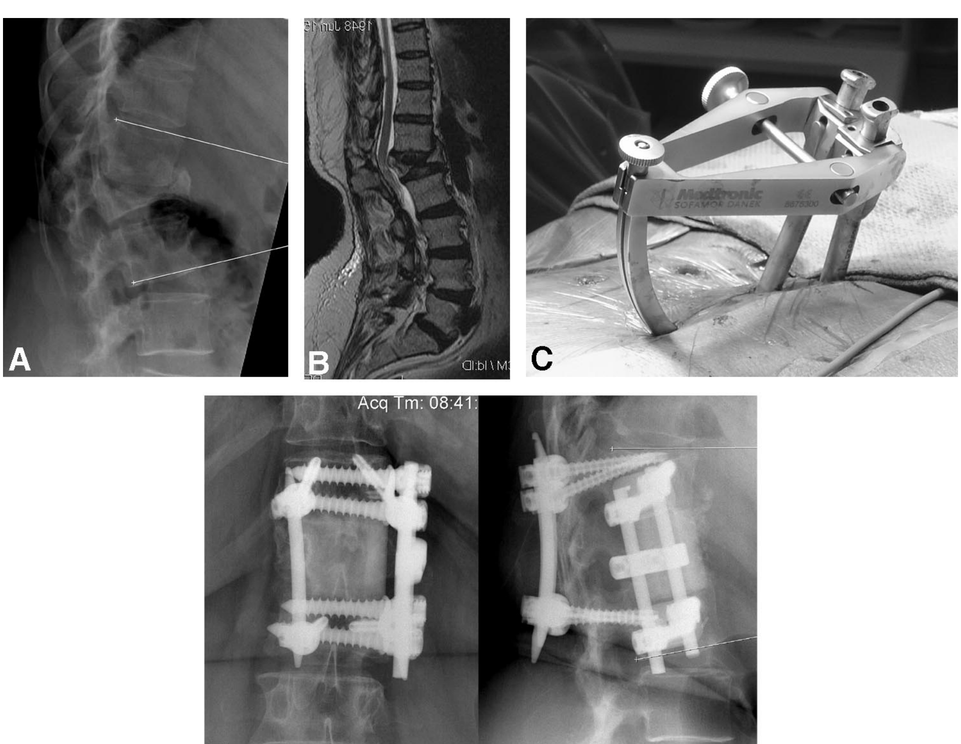


Figure 2. **A**, Upright preoperative lateral radiograph from a 60-year-old woman with mechanical back pain, progressive kyphotic deformity (a 32° kyphosis from T12 to L2 is demonstrated) 9 months following a burst fracture. **B,** Preoperative sagittal T2 MRI demonstrating central contact of the adjacent discs. CT confirmed a nonunion of the vertebral body. **C,** Intraoperative picture demonstrating percutaneous passage of a rod from cephalad (T12) to caudal (L2). Because of this patient's documented osteopenia, percutaneous augmentation of the posterior tension band and anterior construct was performed following a L1 corpectomy and reconstruction. The anterior procedure was performed using a mini-open (14-cm incision) muscle-splitting anterior retroperitoneal-retropleural approach. **D,** Six-month upright postoperative radiographs demonstrating the final construct. Compared with the intraoperative radiographs, the patient had an initial (in-hospital) 5° loss of correction, which has remained stable.

instrumentation was removed *via* a MIS technique once the primary injury healed (at 6–18 months). No adverse events occurred as a direct result of the MIS techniques. No construct failure or loosening occurred. For the burst fractures, angular settling of less than 5° was noted in 3 patients. These patients remained with a net improvement in segmental kyphosis when supine injury films were compared to standing follow-up films.

No differences in long-term outcomes have been shown in these limited case series. Furthermore, there is no Level 1 or 2 evidence showing superiority or inferiority of these MIS techniques compared with conventional techniques.

#### *Percutaneous Vertebral Body Balloon-Assisted Endplate Reduction and Augmentation*

Balloon-assisted techniques have been described for application to "stable" burst fractures with or without percutaneous rods of the segmental fixation.[52] The reader is referred to the article in this focus issue of Spine written by Oner *et al* on the rationale, evolution, and application of this technique. This technique has raised interest and controversy. Our facility with kyphoplasty enables the technical feasibility and subsequent interest of this procedure; however, the type of TL fracture to which this technique typically applies (*i.e.*, stable burst) is often treated nonoperatively by many surgeons (especially in North America).[53] Consequently, the benefit of this technique compared with the established efficacy of nonoperative treatment is unknown. Further, the use of this technique, particularly in higher energy burst fractures, has raised concerns regarding epidural extrusion of cement and dorsal displacement posterior bony fragments. Perhaps the use of novel bone cements or mixtures, anterior balloon placement, percutaneous fixation with ligamentotaxis, axial intraoperative imaging (iso-centric fluoroscopy based computed tomography), and/or mini-open techniques with direct visualization of the epidural space may minimize this potential risk.

#### *Temporary Percutaneous Posterior Fixation*

Timing of surgical stabilization for unstable spine fractures in the polytrauma patient is controversial. Significant literature in the polytrauma long bone experience reflects the reduction of pulmonary and ICU-related complications in patients stabilized early *versus* delayed. Focused experience in spine fracture patients with polytrauma indicates a feasibility and a similar trend in reduction of pulmonary and ICU-related complications.[54] Early surgical intervention for spinal stabilization in the polytrauma patient further stresses the already difficult hemodynamic management of the polytrauma patient. Greater blood loss has been reported for anterior procedures performed less than 48 hours following injury.[54] Anesthesia for posterior spinal fixation is limited by the requirements for prone positioning and associated ventilatory/perfusion mismatch. In addition, postoperative infection is significantly greater in the ICU patient population than the elective patient because of transient malnutrition, post-traumatic immune changes, catheter-related bacteremia, and skin colonization. These factors lead to a higher spinal wound infection rate in the polytrauma spine trauma patients.

Early percutaneous fixation of unstable spinal fractures provides the opportunity to enhance mobilization of the patient. This reduces the need for rotorest beds and associated patient challenges *via* enhanced pulmonary/respiratory care. Early mobilization of the patient reduces nursing care intensity and associated skin pressure challenges.

#### *Current Limitations*

Current MIS techniques as applied to TL trauma are limited by the architecture and mechanics of the current implants and instruments. For example, the current Sextant (Medtronic–Sofamor Danek, Memphis, TN) screws are cannulated multiaxial screws that are affixed to a curved 5.5-mm rod. Screw position is intrinsically limited to an arc by the structural confines of the rod passage and local anatomy. Interval facet joints may require screws to be placed offset in order to avoid impingement. The terminal screws may require higher offset from the facet/pedicle junction to allow for rod passage along an arc and in conjunction with the rod may result in instrumentation prominence, particularly at the TL junction or thoracic spine. This specific implant and others are currently designed for application in the lumbar spine. From a trauma perspective, these systems have limitations regarding multilevel instrumentation at the TL junction and thoracic spine (rod shape, diameter, length, and insertion techniques), reduction capabilities as well as distraction, lordosis, compression or combined vertebral body manipulation. Currently, these systems are going through significant evolution to accommodate the needs for more complex degenerative, traumatic, or oncological applications. The mechanics of the current Sextant instrumentation have shown equivalency to other multiaxial 5.5-mm rod-screw assemblies, including assessment in a corpectomy model. By FDA enclosure, the 5.5-mm rod is indicated for use with anterior column support. Use in the burst fracture model is currently an off-label use. Further, biomechanical assessment of the next generation of this and other systems will be required, particularly in the setting of anterior column deficiency and/or three-column instability.[55] In addition to these mechanical limitations, unlike anterior approaches, MIS techniques for posterior decompression and as well as fusion (posterolateral or multilevel facet fusions) have been applied to TL trauma in a very limited fashion. Therefore, experience with this is very early and comments on reliability and efficacy cannot be made. As with most MIS techniques, there is also an associated learning curve for the application to TL trauma. Increased operative time gradually becomes time neutral and some techniques are time saving (*e.g.*, percutaneous posterior screw fixation).

As with all novel techniques, the potential for increased cost must be considered. To the authors' knowledge, no formal cost-effectiveness study has been reported for these techniques. The additional cost of factors such as endoscopic and minimal access retractors and tools, as well as the increased cost of MIS instrumentation, must be objectively weighed against the potential cost savings of factors such as reduced hospital length of stay, perioperative analgesic use, adverse events, and return to work. To justify the learning curve and potentially increased cost of these techniques, Level 1 (ideally) and 2 studies that demonstrate clinical superiority in perioperative and/or longer-term outcomes are required. Alternatively, if these future studies only demonstrate clinical equivalency, then improved cost-effectiveness compared to conventional techniques should be demonstrated.

### *Future Directions*

As experience with the application of MIS techniques to the management of TL trauma continues to expand, MIS technologies and adjuncts, such as computer-assisted surgery combined with intraoperative three-dimensional imaging, are rapidly evolving. These technologies will not only improve on current applications, they will enable new techniques. The combination of current and novel techniques and technologies holds significant promise for effective minimally invasive management of selected TL injuries.

## ■ Conclusion

It must be emphasized that to successfully achieve the goals of TL trauma management, the application of MIS techniques to TL trauma has to adhere to the basic principles of surgical spinal trauma management (*i.e.*, decompression, reduction/realignment, anterior column support, restoration of the posterior tension band when necessary, and fusion). At present, the specific clinical indications for these less invasive techniques in TL trauma are still being defined and will likely change as surgeons' interest, skill set, and facility with evolving MIS technologies changes. The theoretical benefits of these techniques in the trauma population is sound, however, insufficient or no clinical data exist with which to draw any conclusions as to whether these techniques are associated with superior outcomes compared with conventional techniques. Well-controlled prospective studies assessing both short- and long-term outcomes as well as cost-effectiveness are required to show the potential benefits of these less invasive procedures.

## ■ Key Points

- The clinical effect of soft tissue injury arising from standard open spinal approaches may be a significant source of postoperative pain and functional impairment in the convalescent period as well as a detriment to long-term function.
- The theoretical and practical basis for the application of minimal invasive spinal techniques to spinal trauma is sound; however, insufficient clinical data exist with which to draw any conclusions as to whether these techniques are associated with superior or inferior outcomes compared with conventional techniques.
- Overall experience with the application of these techniques to the management of TL trauma continues to expand.

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