Transforaminal lumbar interbody fusion (TLIF) is used routinely for lumbar arthrodesis and has become fairly well accepted. However, conventional TLIF has been criticized because of the long skin incision and large-area stripping of paraspinal muscles that may induce complications such as muscle scarring, epidural fibrosis, blood loss, injury of nerve and soft tissues. Therefore, conventional TLIF performed via a posterior approach is associated with significant soft tissue injury that can adversely affect the outcomes. X-Tube (Medtronic Sofamor Danek, Memphis) is an expandable tube retractor that can provide additional working space in the posterior paraspinous area to permit endoscopic pedicle screw fixation and interbody fusion through a single tube. This technique is designed to reduce the iatrogenic soft tissue injury that occurs with muscle stripping and retraction during routine spinal exposure. The purpose of this study was to evaluate the efficacy of minimally invasive TLIF in lumbar arthrode-
desis and describe the indications, detail surgical techniques, results and complications for a series of 42 patients treated in our department.

METHODS

Patients
Between June 2004 and May 2006, 42 patients underwent endoscopic TLIF by X-Tube system at our department. There were 17 men and 25 women with the age ranging from 22 to 77 years (mean 51.6 years). The etiologies included L₄-L₅ far lateral disc herniation in 9 patients, L₅-S₁ disc herniation in 5, L₄-L₅ disc herniation combined with degenerative spondylolisthesis in 6, L₅-S₁ disc herniation combined with degenerative spondylolisthesis in 7, L₄ pars defected spondylolisthesis (Ⅰ°) in 5, L₅ pars defected spondylolisthesis (Ⅰ°) in 6, L₄-L₅ disc reherniation in 2 and L₅-S₁ disc reherniation in 2. Twenty-five patients had low back pain combined with lower extremity radicular pain, 8 only had mechanical back pain and 9 had lower extremity radicular pain. The site and extent of disc herniation were affirmed by CT and MRI before surgery. The lumbar segmental stability of the spine was evaluated by flexion-extension film.

Surgical technique

Preoperative preparation
Patient selection before surgery was very important. The advantages and disadvantages of this procedure were carefully explained and the likelihood of conversion to an open procedure was also explained to patients. All patients consented to undergo this procedure.

The operating room should be large enough to accommodate the fluoroscopic and endoscopic instruments comfortably. There should be two trays located at the head and caudal of radiolucent table in order to provide enough place for surgical instruments such as a high-speed, tapered drill, monopole and bipolar cauterys. The room layout should allow the surgeon view the endoscopic procedure comfortably. The author suggested placing two video towers at the head and caudal of the operating table respectively.

Anesthesia and position
Following induction of general anesthesia, the patients were positioned prone, adequate padding by placing under the chest and hip to prevent pressure on the abdominal region.

Location of the incision
After the lateral and anteroposterior (AP) C-arm fluoroscopic images were obtained, the location of the incision could be determined by four lines (A,B,C,D) that were made by four K-wires on the lumbar level of interest. Line A was the line of right pedicle’s lateral border, line B was the line of left pedicle’s lateral border, line C was the line of superior pedicle’s center points and line D was the line of inferior pedicle’s center points. The lines of crossing points on both sides were the location of incisions (Fig.1), which was approximately 3.2-3.5 cm long and 3.5-4.5 cm lateral to the midline (Fig.2) and then marked it. The procedure was carried out on the side ipsilateral to the worst radiculopathy.

Tubular retraction (X-Tube) placement
The back of the patient was washed and draped in a standard surgical fashion. A vertical incision was made at the pre-marked position. A spinal needle was inserted 10-15 degree angle lateral to the midline in order to identify the bony anatomies. Then, a periosteum detacher was placed following the needle for stripping soft tissue covering the lateral facet and adjacent structures. In this procedure, the periosteum detacher should be sticked tightly to the bone and stripped repeatedly and limited in the lateral border of articular process, otherwise, it might injure the nerve root and vascular bundle out of vertebral canal. Step-dilators were passed over the needle to dilating the muscle and fascia sequentially. A suitable X-Tube endoscopic retractor of appropriate length was placed over the last step-dilator (Fig.3). The retractor was turned to the optimal position under fluoroscopic guidance and then a flexible arm was attached to the tubular retractor to hold it firmly in place. The distal skirt of the retractor was then expanded in the longitudinal direction by a corresponding expandor. The retractor should be suppressed downward by an assistant during expanding so as to prevent soft tissue from creeping under the tubular retractor and obstructing the operative view. Once this occurred, the retractor should be removed and placed again until obtained a good operative view.

Endoscope insertion
After the retractor was well placed, the endoscope was inserted into the retractor, secured to the tubular retractor using the locking arm on the ring attachment and adjusted the position. If the lightness of operative view was not enough, the cold light source can be used to obtain the optimal view.
Decompression A monopole electric coagulator with a long tip was used to remove the remaining muscle and soft tissue overlying the medial facet and adjacent lamina. The granulation tissue in pars defected spondylolysis was cleared. With the facet joint and the basilar part of transverse process well visualized (Fig.4), a high-speed drill was used to decorticate the facet joint and the transverse process to thin the lamina and the facet complex. After adequate drilling, a Kerrison endoscopic laminectomy rongeur or endoscopic bone chisel was then used to remove the facet joint from the lateral border to midline. The removed bone was denuded of all soft tissues, morselized, and then used for interbody graft material. When the post-lateral wall of nerve root canal was removed, the ligamentum flavum was opened by an angled endoscopic curette or nerve hook and removed by a rongeur, and the nerve root was then exposed. The space of nerve root canal was explored by a globular, angled nerve probe, and a Kerrison rongeur was used to begin the decompression if there was compression of granulation and bony tissue. A nerve dissector was used to free the nerve root carefully. Bleeding from small epidural veins and the edge of the flavum was controlled via long-tipped endoscopic bipolar cautery. The nerve root was then retracted medially using a nerve retractor. The underlying disc space was then presented.

Lumbar interbody fusion A sharp annulotomy was made with a sheathed endoscopic microknife. The herniated disc was then removed with a straight/angled pituitary rongeur in a standard fashion (Fig.5). Straight endoscopic abrasors were inserted into the disc space to remove the nucleus pulposus totally by rotation of these abrasors. Once this had been done, cartilaginous material was removed from the endplates by an angled endoscopic drawknife until bleeding cancellous bone was exposed. The author suggested that all the tools should be inserted into the intradisc region under fluoroscopic guidance and less than 3 cm in order to avoid the incident injury of great vessels in abdominal cavity (Fig.6). After douche of the intervertebral space, bean-like local autologous bone graft which was attained from removed bone or iliac spine was placed into the interspace and impacted by an endoscopic depressor (Fig.7). Cage (Telamon) with bone graft was a good choice for interbody fusion, and for one cage, the optimal position was the center of interspace. The hole of disc was addressed with bone wax or Gelfoam. Additional autograft bone was placed between decorticated transverse processes.

Reduction and fixation (Fig.8) Under fluoroscopic guidance, the pedicle screw entry points (junction of the midpoint of the transverse process with the lateral facet) were identified. A high-speed drill was used to decorticate the superficial bone. The pedicle holes were then drilled and tapped. A pedicle probe was inserted at 10-15 degree angle to the longitudinal axis of spine and followed the trend of pedicles. The tubular retractor could be angled by loosing the flexible arm so that the screws could be placed conveniently. Then, pedicle screws of appropriate size were placed along the pedicle holes under real-time fluoroscopic guidance. The screws were paralleled with superior endplate and stopped at 2/3 body of vertebra. Through the retractor, by a plate inserter, the angled Dynalok (Medtronic Sofamor Danek, Memphis) plate was placed over the screws and the screw heads were then tightened. The endoscope was removed, and the retractor was withdrawn from the wound after recovery. Reduction of a spondylolisthesis could be accomplished after removal of the retractor because of the long screw cauda. The plate was then placed (angled) through the separate skin incision and the screw nuts were placed, too. Tighten the distal screw and then the superior screw subsequently. The contralateral side fixation was accomplished under X-Tube system with inter-processus transversus bone graft fusion and the TLIF procedure was also performed on the contralateral side when there was radiculopathy and/or segmental instability.

Drainage and saturation Normal saline of 250 ml with cidomycin 160 000 IU were used to douche the surgical site and sucked by endoscopic suctor. Any bleeding in the wound was controlled with the bipolar forceps. A drainage rubber tissue usually placed in the wound, but a silica gel drainage tube was used when there was much bleeding during the operation. The fascial incision was closed, and the skin was closed with 3-4 sutures.

Postoperative care Keep the drainage well in order to avoid haematocele and infection. The antibiotc drug was used routinely for 7 to 10 days and the glucocorticoid, dehydrating and neurotrophy agents were used properly to relieve nerve edema and accelerate neurofunctional rehabilitation in the first week.
RESULTS

Twenty-three patients underwent unilateral fixation and 19, bilateral fixation. The average operative time was 240 minutes (range 110-320 minutes). The mean estimated blood loss was 140 ml (range 80-420 ml). The mean size of skin incision was 3 cm (range 2.8-3.2 cm). The average hospital stay was 12.5 days (range 5-25 days) in 41 patients except one who stayed 56 days because of wound haematocoele and infection. Thirty-seven of 42 patients (88.1%) were followed up, in whom 9 patients were followed up for two years, 16 for one year, and 12 for half a year. The clinical outcomes were evaluated using the Visual Analog Scale (VAS), Oswestry Disability Index (ODI) and Nakai criteria. All patients with preoperative radiculopathy and mechanical low back pain (LBP) had resolution of their symptoms postoperatively.

From 6.5 cm of the preoperative mean VAS score of LBP decreased to 3.2 cm at 6 months ($P<0.05$), 2.7 cm at 1 year ($P<0.01$) and 2.1 cm at 2 years ($P<0.01$) postoperatively. The mean VAS score of radiculalgia decreased from 8.3 cm preoperatively to 4.2 cm at 6 months ($P<0.05$) and 3.1 cm at 1 year ($P<0.01$) and 2.1 cm at 2 years ($P<0.01$) postoperatively. The mean Oswestry score decreased from 56% preoperatively to...
32% at 6 months ($P<0.05$), 21% at 1 year ($P<0.01$) and 15% at 2 years ($P<0.01$) postoperatively. Using the Nakai criteria, the clinical outcomes were graded excellent in 23 patients (62.2%), good in 11 (29.2%) and fair in 3 (8.6%). Twenty-five patients who had 1 year follow up showed remarkable bony interbody fusion on the X-ray film and 7 of the 12 patients who only had 6-month follow up showed remarkable bony interbody fusion. Although there was no significant interbody fusion in the other 5 cases, no patient appeared to have significant clinical symptoms or radiographic evidence of vertebral displacement and loose instrumentation.

There were 5 complications in 42 cases. Two patients had residual radicular numbness after transient radicular pain postoperatively and complete remitted 3 months later. One patient presented with progressive radicular pain, weakness of extensor hallucis longus, and lateral leg hyperalgesia and foot dorsum on the contralateral side 3 days after surgery. During reoperation (the 7th day after surgery), we found that the nerve root was compressed by granulation after decompression of the ipsilateral side and then was resolved with contralateral TLIF procedure. One patient presented with incision dehiscence and focal skin necrosis and then healing by removal of local skin and suturation. One patient presented deep wound infections because of hematoma which caused by inadequate drainage and resolved with debridement. The VAS score of radiculalgia decreased from 6.7 cm preoperatively to 3.2 cm, the average Oswesty score decreased from 48% preoperatively to 23% and good by Nakai criteria evaluated at 1 year postoperatively.

**DISCUSSION**

**Advantages of TLIF under X-Tube**

Unilateral TLIF procedure was initially reported by Harms et al.\(^5\) and this approach offers several advantages over the posterior lumbar interbody fusion (PLIF) technique and has been accepted extensively. Although the conventional TLIF and PLIF have good outcomes, they are associated with significant long-term postoperative low back intractable pain and soft tissue and muscle stripping and retraction that occurs during routine surgical exposure. Kawaguchi et al.\(^2\) found that elevated serum level of creatine phosphokinase, a direct marker of muscle injury, is related to the retraction duration and pressure. Styf et al.\(^3\) reported that the retractor blades can increase intramuscular pressure to ischemic levels and cause iatrogenic muscle injury. The deleterious effects of the extensive muscle stripping and retraction have been well reported as the main reason for postoperative persistent pathologic changes in paraspinous muscles.\(^6\) These side effects of open lumbar surgery occur so commonly and called the term “failed back surgery syndrome (FBSS)”.\(^7,8\) Therefore, it is significant to reduce the iatrogenic soft tissue injury that occurs with muscle stripping and retraction during routine spinal exposure.\(^9,10\) The goal of minimally invasive spinal surgery is to achieve the same objective as the conventional procedure via a less traumatic approach and reduce the physical and psychic injury.

Endoscopic X-Tube technique is a minimally invasive approach which is developed based on METRx technique. The tubular retractor is mobile and can be manipulated to view several adjacent spinal levels through a 2.8-3.0 cm skin incision following sequential soft tissue dilation and expanding.\(^11,12\) With expanding the retractor distal skirt, variable magnification of endoscope and long, tapered instrumentation designed specifically for use in a small working space, the operative procedure is more safe, effective and minimally invasive than open procedure.\(^13\) In this study, the author successfully performed the minimally invasive TLIF procedure in 42 patients using the X-Tube system. Patients appeared to have less postoperative pain and minimal tissue trauma. As a result, the scores of VAS and ODI in our series indicate these advantages.

**Complications and managements**

**Bleeding** In the minimally invasive TLIF procedure, bleeding usually occurs during soft tissue stripping, facetectomy and decompression. Unlike microendoscopic discectomy procedure in which the soft tissue stripping always limited on the lamina of lumbar vertebra, the stripping in minimally invasive TLIF procedure is extensive especially on the facies articularis ossium and then injure to the intervertebral foramen nerve and vascular bundle easily if the periosteum detacher inserts too deep and penetrates the intertransverse membrane. When bleeding cannot be controlled, insert finger into wound in order to explore the anatomic structure and hemostasis by compression. The thrombin-soaked Gelfoam/ absorbable hemostatic gauze should be used for additional hemostasis if necessary.
Once the bleeding is uncontrolled, convert to open procedure immediately. During facetectomy and decompression, bleeding in intervertebral foramen and disc region are also difficult to control. To avoid this bleeding, we tend to retract and expose the nerve root carefully in neural foramen, and bipolar coagulation, hemostatic gauze and clips were used for hemostasis. Using bipolar coagulation, we took care to protect nerve root and dorsal ganglion. The intensity of cautery was controlled in a safe range. Postoperative hyperpathia occurred in one patient and anesthesia on the lateral of left leg may, in fact, be related to the overuse of bipolar coagulation in neural foramen. Therefore, when there is bleeding in the neural foramen, the thrombin-soaked Gelfoam or absorbable hemostatic gauze should be used first. Furthermore, as the limited tactile feedback and two-dimensional video image of three-dimensional anatomy, the depth of instruments insertion in the wound is inadequately handled. We suggest that all the tools should be inserted into the intradisc region under fluoroscopic guidance in order to avoid the incident injury to great vessels in abdominal cavity. If bleeding at the disc site is severe and/or hypotension exists, indicating that the major vascular injury occurs, blood transfusion should be conducted immediately, and turn the patient to a dorsal position and the exploratory laparotomy will be performed.

Nerve root injury  Nerve root injury can occur in neural foramen exposal, discectomy, screws and interbody spacer placement. The primary risk of the foramen exposal procedure is inadvertent nerve root injury during drilling the articular process because of over drilling and regional high temperature. To avoid this injury, we recommend leaving a thin layer of cortical bone during drilling the articular process and this bone is then removed with a curette from the lateral border to the midline. The normal saline of low temperature is used to reduce the regional temperature. During discectomy, screws and interbody spacer placement, we perform a minimal amount of retraction carefully on the lateral thecal sac and protect the exiting root with a small dissector.

Malposition of pedicle screws  Placement of pedicle screws through a small tubular corridor limits the exposure and orientation. In addition, the metal tubular retractor is not radiolucent and surgeons cannot place pedicle screws at A-P position, therefore, it is difficult to place pedicle screws through this retractor. To compensate for this, we prefer to expose the anatomic structure of facet joint first and mark the pedicle screw entry points before decompression so as to provide an anatomic reference point to the surgeons. A drill is recommended to create entry holes at marked points early. The fluoroscopic guidance is an excellent method to check the position of the pedicles and screws, so this procedure of placement must be performed under the fluoroscopic guidance. The tubular retractor can be regulated by loosing the flexible arm for manipulation conveniently. Fortunately, there was no malposition of pedicle screws in our study.

Indications and contraindications of minimally invasive TLIF (X-Tube)  Based on the results of this study, the authors suggest the following indications for minimally invasive TLIF: 1) single level lumbar disc herniation with concurrent lumbar unsteadiness; 2) single level lumbar stenosis with possible postoperative steadiness; 3) far lateral disc herniation and need for a facetectomy; 4) single level degenerative spondylolisthesis (≤ Ⅰ°); 5) pars defected spondylolysis (≤ I °); 6) recurrent lumbar disc herniation. The surgery contraindications include: 1) multi-level lumbar disc herniations and lumbar stenosis with concurrent lumbar unsteadiness; 2) multi-level lumbar unsteadiness or spondylolysis; and 3) spondylolysis (> Ⅰ°).

Conclusion  Patient selection is the key to a successful surgery no matter in conventional TLIF or minimally invasive TLIF. As the limited tactile feedback, two-dimensional video image of three-dimensional anatomy and the manual dexterity needed to manipulate instruments through a small tubular corridor, there is a very steep learning curve for this technique. A thorough knowledge of the surgical anatomy, experience of open surgery and ability to mastering hand-eye coordination are critical for success of endoscopic surgery. Therefore, the patient selection for this surgical fashion should be more strict and cautious than open procedure and consistent with the surgeon’s experience and surgical abilities.

REFERENCES


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