Recent Advances in Technique and Clinical Outcomes of Minimally Invasive Spine Surgery in Adult Scoliosis

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Abstract

Objective: Conventional open spinal surgery of adult scoliosis can be performed from anterior, posterior, or combined approach. Minimally invasive spine surgery (MISS) was developed for the purpose of reducing the undesirable effects and complications. This review aimed to make a brief summary of recent studies of the approach and clinical outcomes of MISS in adult scoliosis.

Data Sources: We conducted a systematic search from PubMed, Medline, EMBASE, and other literature databases to collect reports of surgical methods and clinical outcomes of MISS in treatment of adult scoliosis. Those reports were published up to March 2017 with the following key terms: “minimally invasive,” “spine,” “surgery,” and “scoliosis.”

Study Selection: The inclusion criteria of the articles were as followings: diagnosed with adult degenerative scoliosis (DS) or adult idiopathic scoliosis; underwent MISS or open surgery; with follow-up data. The articles involving patients with congenital scoliosis or unknown type were excluded and those without any follow-up data were also excluded from the study. The initial search yielded 233 articles. After title and abstract extraction, 29 English articles were selected for full-text review. Of those, 20 studies with 831 patients diagnosed with adult DS or adult idiopathic scoliosis were reviewed. Seventeen were retrospective studies, and three were prospective studies.

Results: The surgical technique reported in these articles was direct or extreme lateral interbody fusion, axial lumbar interbody fusion, and transforaminal lumbar interbody fusion. Among the clinical outcomes of these studies, the operated levels was 3–7, operative time was 2.3–8.5 h. Both the Cobb angle of coronal major curve and evaluation of Oswestry Disability Index and Visual Analog Scale decreased after surgery. There were 323 complications reported in the 831 (38.9%) patients, including 150 (18.1%) motor or sensory deficits, and 111 (13.4%) implant-related complications.

Conclusions: MISS can provide good radiological and self-evaluation improvement in treatment of adult scoliosis. More prospective studies will be needed before it is widely used.

Key words: Adult Scoliosis; Complications; Minimally Invasive Spine Surgery; Outcomes; Surgical Methods

INTRODUCTION

Adult scoliosis is defined as a coronal deformity with a Cobb angle >10° in a skeletally mature patient. It can be divided into two broad types: degenerative scoliosis (DS) and adult idiopathic scoliosis.[1,2] The aims of surgical treatment of adult scoliosis are to obtain coronal and sagittal alignment, pain relief, and solid fusion.[3] Conventional open spinal surgery, which could improve Oswestry Disability Index (ODI)[4] and achieve pain relief, functional restoration, and satisfaction,[5] is widely used in the operative decompression and correction of the deformity. To decompress and reconstruct the alignment of the spine, multilevel surgery is usually required. This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as the author is credited and the new creations are licensed under the identical terms.

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needed, and this is often associated with large quantity of blood loss and longer time for anesthesia which are harmful to elderly people, especially who are suffered from complications.\(^{[10]}\) Meanwhile, large operative scars may bring high psychological and physiological burden to patients.\(^{[4-8]}\) The incidence of complications for conventional surgery was reported from 20% to 80% in recent studies.\(^{[6,9,10]}\) For the purpose of reducing these undesirable effects and complications caused by traditional open spinal surgeries, the minimally invasive spine surgery (MISS) was developed.\(^{[11]}\)

After the conception of MISS was proposed in the 1990s,\(^{[12,13]}\) the use of MISS in the treatment of adult scoliosis has been widely reported. Compared with traditional open surgery which may have a series of perioperative complications such as excessive blood loss, infection, neurological injury, incisional pain, vascular injury, retrograde ejaculation, and ureteral and bladder injury,\(^{[8,14,15]}\) MISS has the advantages of less pain, shorter hospital stay, earlier mobilization, and less infection.\(^{[16-19]}\) However, the correlation between this new surgery and favorable outcomes has not been fully established.\(^{[20]}\) This review aimed to make a brief summary of recent studies of the approach and clinical outcomes of MISS in adult scoliosis.

**Surgical Technique and Clinical Outcomes**

Since the introduction of minimally invasive transforaminal lumbar interbody fusion (MI-TLIF), the technical feasibility and safety have been well established both in primary and revision surgery.\(^{[17,21,22]}\) This is a technique of MISS with several advantages over traditional open procedure such as less postoperative back pain, less adjacent tissue damage, less blood loss, shorter hospital stay, and rapid recovery.\(^{[23-25]}\) However, it is not widely used or even regarded as a relative contraindication in patients with fixed coronal and/or sagittal deformities, especially in those who need to be operated in more than three segments.\(^{[20,26]}\)

To overcome the disadvantages of traditional open and posterior approach, the MI axial lumbar interbody fusion (AxialLIF), which is a presacral retroperitoneal approach, was introduced.\(^{[27]}\) It is not only an alternative with the potential to expand the narrowed disc space and restore normal disc height with decreased blood loss, operative time, and hospital stay but also a good choice for overweight patients.\(^{[28,29]}\) To our knowledge, single use of AxialLIF in treatment of scoliosis was seldom reported. Limited reports were of AxialLIF associated with additional anterior or posterior pedicle screw instrumentation.\(^{[28,30]}\)

A recent advancement in the field of MISS is the lateral transpsoas approach for lumbar interbody fusion that is extreme lateral interbody fusion (XLIF) or direct lateral interbody fusion (DLIF); there have been some reports of their uses in surgical treatment of lumbar DS. This approach is a lateral retroperitoneal, transpsoas approach to the anterior disc space allowing for complete discectomy, distraction, and interbody fusion. Because it does not penetrate into abdominal cavity as traditional laparoscopic surgery, and the cage can be located into the intervertebral disc without the incision of anterior and posterior longitudinal ligament, less damage to the adjacent tissues can be achieved.\(^{[31-38]}\)

In this series of patients, 831 patients of twenty studies of MISS in adult DS and adult idiopathic scoliosis were collected. The surgical techniques reported were DLIF or XLIF, AxialLIF, and TLIF. Among the clinical outcomes of these studies, the operated levels was from 3 to 7, and operative time was from 2.3 to 8.5 h. Both the Cobb angle of coronal major curve and evaluation of ODI and Visual Analog Scale were decreased after surgery.\(^{[16,30,35-52]}\) The results of recent studies of MISS for adult scoliosis and their outcomes are shown in Table 1 and Table 2, respectively.

**Complications of Minimally Invasive Spine Surgery in Adult Scoliosis**

MISS or MISS plus other instrumentation approaches can have several complications compared to conventional open spinal surgery. Traditional open surgery had high complication incidence rate from 20% to 80%, such as pain, swelling of incision, large amount of blood loss, and even death.\(^{[8,14,53-55]}\) Several factors were correlated strongly with the incidence of complications, such as age, number of levels operated, and time of operation.\(^{[20,56]}\) MISS could avoid some disadvantages of traditional procedure; it also had certain complications compared to open surgery. MISS plus other instrumentation approaches experienced a higher incidence rate of complications than MI procedure alone. In one report, the rate was 37.9% compared to 19.2% (\(P = 0.045\)).\(^{[38]}\) In this section, the complications of MISS in adult scoliosis treatment are summarized into three parts.

**Systemic complications**

Systemic complications include motor or sensory deficits, cardiovascular system (CVS), digestive system, respiratory system, central nerve system (CNS), and urinary system.

Motor or sensory deficits are the most common disadvantages of MISS, especially in lateral transpsoas approach, because the femoral nerve and the lumbar plexus nerve roots may be damaged during the operation. Among twenty studies, the occurrence of motor or sensory deficits was 150 (18.1%) in all 831 patients.\(^{[16,30,35-52]}\)

The incidence of complications of CVS among these studies was 1.1% (9 cases in all 831 patients), such as atrial fibrillation, myocardial infarction, deep vein thrombosis,\(^{[38]}\) congestive heart failure,\(^{[38]}\) and pulmonary embolism.\(^{[35]}\)

The incidence of complications of the digestive system was 1.1% (9 in all 831 patients), including intraoperative bowel injury, abdominal viscera, postoperative ileus, and gastrointestinal bleed.\(^{[38]}\)

Eight patients (1.0% in all 831 cases) had respiratory system complications such as pneumothorax, pleural effusion,\(^{[35,38,41]}\) pulmonary hypertension, and pneumonia.\(^{[38]}\)

The incidence rate of CNS complication in all 831 patients reported was 0.7% (6 cases), including idiopathic...
Table 1: Summary of recent studies of MISS in adult scoliosis

| Author          | Year  | Patients number | Average age (years) | Type of scoliosis | Surgical technique                                      | Follow-up (months) |
|-----------------|-------|-----------------|--------------------|-------------------|---------------------------------------------------------|--------------------|
| Tormenti et al. | 2010  | 8               | 60.0               | Thoracolumbar DS  | XLIF + open posterior TLIF                             | 10.5               |
| Dakwar et al.   | 2010  | 25              | 62.5               | Thoracolumbar DS  | Lateral retropertoneal transposas                       | 11.0               |
| Wang and Munir  | 2010  | 23              | 64.4               | 17 LDS and 8 others | Anterior transposas MISS + posterior instrumentation    | 13.4               |
| Isaacs et al.   | 2010  | 107             | 68.4               | DS                | XLIF + anterior/posterior instrumentation               | 1.5                |
| Anand et al.    | 2010  | 28              | 67.7               | Adult idiopathic scoliosis + DS | XLIF/DLIF/AxiaLIF + posterior instrumentation          | 22.0               |
| Kelleher et al. | 2010  | 16              | 67.0               | DS                | MISS lumbar laminoplasty (bilateral decompression from a unilateral approach) | 32.0               |
| Acosta et al.   | 2011  | 8               | –                  | DS                | DLIF + PSF                                             | 21.0               |
| Akbarnia et al. | 2011  | 16              | 56.0               | Adult idiopathic scoliosis + DS | Lateral retropertoneal transposas LIF                  | 24.0               |
| Karikari et al. | 2011  | 30              | –                  | DS                | XLIF, TLIF or XLIF + posterior instrumentation         | –                  |
| Anand et al.    | 2013  | 71              | 64.0               | DS + idiopathic scoliosis + iatrogenic scoliosis        | DLIF + AxiaLIF + posterior instrumentation            | 39.0               |
| Phillips et al. | 2013  | 107             | 68.0               | DS                | DLIF, or XLIF + posterior instrumentation             | 24.0               |
| Deukmedjian et al. | 2013 | 27              | 61.0               | DS                | LIF + posterior instrumentation                        | 17.0               |
| Caputo et al.   | 2013  | 30              | 65.9               | DS                | XLIF + posterior instrumentation                       | 14.3               |
| Anand et al.    | 2014  | 90              | 63.5               | ASD               | DLIF, or DLIF + AxialIF, + posterior instrumentation   | 40.0               |
| Haque et al.    | 2014  | 42              | 61.7               | ASD               | LIF + TLIF + anteriorinterbody fusion                  | 25.7               |
| Castro et al.   | 2014  | 35              | 68.2               | DS                | LIF                                                     | 24.0               |
| Anand et al.    | 2014  | 46              | 67.0               | DS + adult idiopathic scoliosis + iatrogenic scoliosis  | Segmental multilevel percutaneous pedicle screw fixation, correction, and fusion; lateral transposa discectomy and interbody fusion; and transsacral fixation and fusion | 24.0               |
| Khajavi and Shen | 2014  | 24              | 70.1               | DS                | LIF, or LIF + posterior instrumentation               | 24.0               |
| Manwaring et al. | 2014 | 36              | 64.3               | DS                | LIF + posterior instrumentation                        | 22.9 (non-ACR)     |
| Anand et al.    | 2014  | 50              | 61.0               | Adult idiopathic scoliosis                             | DLIF, or DLIF + posterior instrumentation            | 48.0               |

DS: Degenerative scoliosis; ASD: Adult spinal deformity; LDS: Lumbar degenerative scoliosis; PSF: Posterior spinal fusion; LIF: Lateral interbody fusion; DLIF: Direct lateral interbody fusion; XLIF: Extreme lateral interbody fusion; AxialIF: Axial lumbar interbody fusion; TLIF: Transforaminal lumbar interbody fusion; -: Not available; ACR: Anterior column release; MISS: Minimally invasive spine surgery.

cerebellar hemorrhage,[39,52] cerebral spinal fluid leakage,[37] meningitis,[35] and cerebellar hemorrhage.[36]

Only four (0.5%) cases of urinary system damage were described in all 831 patients, one intraoperative renal capsule injury,[41] one urinary tract infection,[38] and one retrocapsular renal hematoma.[30]

Generalized complications

Twenty-six (3.1%) generalized complications have also been described in all 831 patients including superficial wound dehiscence,[52] wound infection,[44] or sepsis,[35] postanesthesia delirium and hyponatremia,[48] and rhabdomyolysis.[16]

Implant-associated complications

The complications of instrumentation among twenty studies occurred in 111 cases (13.4% in all 831 patients), including misplaced hardware,[32] pseudarthrosis related with screw implantation and hardware revision,[46,49] cage subsidence or micromotion,[48] nonunion,[45] hardware revision,[43] screw prominence,[39] implant failure,[16] cage dislodgment,[41] and asymptomatic proximal screw fracture.[30]

There were 323 complications reported in the 831 patients (38%), including 150 motor or sensory deficits (18.1%) and 111 implant-related complications (13.4%). The complications of these studies are shown in Table 3. Not all open surgery complications could be avoided in MISS. The complications may restrict it from routine use in the surgical treatment of scoliosis.[35‑39] Furthermore, a learning curve lies in it and appropriate training is needed before practicing this new approach.[23,60]

Conclusions

The MISS provides the surgeon with an alternative option when dealing with adult scoliosis. The primary clinical results showed that, MISS can be effective in both
Table 2: Summary of clinical outcomes of MISS in adult scoliosis

| Author                  | MOL Operative time (h) | AEBL (ml) | AVT (cm)                      | Major curve changed (cobb angle) |
|-------------------------|------------------------|-----------|-------------------------------|---------------------------------|
|                         |                        |           |                               | Coronal                        |
|                         |                        |           |                               | Preoperation | Postoperation | Preoperation | Postoperation |
| Tormenti et al.[35]     | 3.9                    | -         | 3.6                           | 1.8                             | 38.5         | 10.0         |
| Wang and Mummaneni[37]  | 3.7                    | 6.7       | 477                           | -                               | 31.4         | 11.5         | 37.4         | 45.5         |
| Issacs et al.[33]       | 4.4                    | 3.0       | 62.5% <100                    | -                               | 24.3         | -            | -            | -            |
|                         |                        |           | 8.4% >300                     | 241 (anterior)                  | -            | 22.0         | 7.0          | -            |
| Anand et al.[39]        | >3.0                   | 3.9       | 241 (anterior)                | 231 (posterior)                | -            | 21.4         | 9.7          | -            |
| Dakwar et al.[34]       | 4.8                    | 8.5       | 150                           | -                               | 47.0         | 17.0         | -            | -            |
| Akbarnia et al.[31]     | -                      | -         | -                             | -                               | -            | -            | -            | -            |
| Kelleher et al.[30]     | -                      | -         | -                             | -                               | -            | -            | -            | -            |
| Acosta et al.[34]       | -                      | -         | -                             | -                               | -            | -            | -            | -            |
| Anand et al.[39]        | 4.4                    | 4.9*      | 412*                          | 3.0†                           | 24.7         | 9.5          | -            | -            |
|                         |                        |           |                               | 314‡                           |              |              |              |              |
|                         |                        |           |                               | 4.1†                           |              |              |              |              |
|                         |                        |           |                               | 357†                           |              |              |              |              |
| Phillips et al.[42]     | 3.0                    | 3.0       | -                             | 20.9                           | 15.2         | 27.7         | 33.6         | -            |
| Deukmedjian et al.[44]  | -                      | -         | -                             | 26.9                           | 12.8         | -            | -            | -            |
| Caputo et al.[45]       | 4.2                    | -         | 23.6                          | 9.5                             | 20.2         | 5.6          | 43.5         | 48.5         |
| Anand et al.[40]        | 6.3                    | -         | -                             | -                               | 35.8         | 13.9         | 45.4         | 48.6         |
| Haque et al.[47]        | -                      | 7.7       | 507                           | 32.0                           | 13.1         | 33.8         | 39.4         | -            |
| Castro et al.[48]       | 3                      | 2.3       | 54                            | 21.0                           | 12.0         | 33.0         | 41.0         | -            |
| Anand et al.[49]        | -                      | -         | -                             | -                               | -            | -            | -            | -            |
| Khajavi and Shen[49]    | 3.3                    | 3.6       | 68                            | 27.7                           | 16.6         | 31.8         | 44.0         | -            |
| Manwaring et al.[13]    | 3.8                    | -         | -                             | 28.9 (non-ACR)                 | 12.9 (non-ACR)| -            | -            | -            |
|                         |                        |           |                               | 28.9 (ACR)                     | 12.9 (ACR)   |              |              |              |
| Anand et al.[52]        | 7.0                    | 5.6*      | 613*                          | 8.0†                           | 42           | 16           | -            | -            |
|                         |                        |           |                               | 763‡                           |              |              |              |              |
|                         |                        |           |                               |                                  |              |              |              |              |

| Author                  | ODI Preoperation | Postoperation | VAS Preoperation | Postoperation |
|-------------------------|-----------------|---------------|-----------------|---------------|
| Tormenti et al.[35]     | 8.8             | 3.5           | 7.3             | 3.4           |
| Wang and Mummaneni[37]  | 7.3             | 3.4           | 7.1             | 3.1           |
| Issacs et al.[33]       | -               | -             | 8.1             | 2.4           |
| Anand et al.[39]        | 53.6            | 29.9          | 6.5             | 2.5           |
| Dakwar et al.[34]       | 60.0            | 24.0          | 35.7            | 22.0          |
| Akbarnia et al.[31]     | 50.7            | 31.5          | -               | -             |
| Kelleher et al.[30]     | 53.0            | 22.0          | -               | -             |
| Acosta et al.[34]       | 50.3            | 49.7          | 6.4             | 4.3           |
| Anand et al.[39]        | 53.5            | 34.7          | 7.5             | 4.6           |
| Phillips et al.[42]     | -               | -             | 6.2             | 3.1           |
| Deukmedjian et al.[44]  | 51.0            | 29.0          | 8.5             | 2.7           |
| Caputo et al.[45]       | 47.6            | 21.8          | 6.6             | 2.8           |
| Anand et al.[49]        | 48.4            | 24.4          | 7.0             | 2.9           |
| Khajavi and Shen[49]    | 44.0            | 22.0          | 5.7             | 2.9           |

*One stage; †Two stage–DLIF; ‡Two stage AxiaLIF; §Two stage. MOL: Mean operated level; AEBL: Average estimated blood loss; AVT: Apical vertebral translation; ODI: Oswestry Disability Index; VAS: Visual analog scale; ACR: Anterior column release; --: Not available; MISS: Minimally invasive spine surgery.
| Author | Systemic complications | Motor or sensory deficits |
|--------|------------------------|--------------------------|
| Akbarnia et al. | implant-associated complications | Systemic complications |
| | | | | | | Generalized complications |
| | | | | | | Implant-associated complications |
| Anand et al. | 3 abdominal weakness | 3 quadriceps weakness | 9 thigh numbness | 8 thigh pain | 1 pleural effusion | – | – | 3 hardware revision | 14 pseudarthrosis | 46 supplemental fixation |
| Tormenti et al. | 1 renal hematoma | 1 ileus | – | 1 cerebellar hemorrhage | – | – | 1 wound infection | 1 intraoperative hemodynamic instability | – |
| Wang and Mummaneni | 2 pneumothorax | 1 CSF leakage | 1 AF | – | 1 screw pullout | – | – | 1 rhabdomyolysis | 1 subsidence | – |
| Dakwar et al. | 1 kidney laceration | 4 ileus | 1 GI bleed | 1 pleural effusion | 1 pneumonia | 1 pulmonary hypertension | – | 1 DVT | 3 AF | 1 CHF | 1 MI | 4 pseudarthrosis | 1 screw prominence | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 hardware revision | 14 pseudarthrosis | 46 supplemental fixation |
| Phillips et al. | 1 idiopathic cerebellar hemorrhage | – | – | – | – | – | 2 wound dehiscence | 1 wound infection | 1 osteomyelitis | 1 discitis | 1 proximal junctional kyphosis | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 hardware revision | 14 pseudarthrosis | 46 supplemental fixation |
| Deukmedjian et al. | – | – | 1 lateral incisional hernia | – | – | 1 AF | 2 wound breakdown | 1 pedicle fracture | 2 rupture of the anterior longitudinal ligament | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 3 hardware revision | 7 pseudarthroses |
radiological and self-evaluation outcomes, but it also has several complications. More studies are needed to provide further favorable results before it is widely used to compare with traditional open surgery.

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There are no conflicts of interest.

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