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Review Article

Minimally invasive spinal surgery in spinal infections – A review

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ABSTRACT

The incidence of hematogenous vertebral osteomyelitis is increasing parallel to longer life expectancies, chronic disease, better diagnostic techniques, indwelling intravascular catheters and immunosuppressive therapy. In Sub-Saharan African countries the number of reported spinal tuberculosis cases has tripled secondary to the Acquired immunodeficiency syndrome pandemic. Most patients with spinal infections can be successfully treated non-operatively. Medical management is particularly successful before significant bony destruction has taken place. In patients that require surgical intervention several recent studies have shown that MISS, applied to the treatment of spinal infections, demonstrates significant advantages over the open approaches. In the thoracic spine the exact site of the focus of infection and the extent of kyphosis determines the ideal surgical approach. The following MISS approaches to the thoracic spine are currently utilized 1. Mini-thoracotomy; 2. Mini-open thoracoscopically assisted thoracotomy (MOTA); 3. Video-assisted thoracoscopic surgery (VATS); 4. Video assisted telescopic operating microscope assisted thoracotomy (VITOM thoracotomy); and 5. Percutaneous thoracic fixation. Regarding infections of the lumbar spine neurological complications are uncommon as compared to infection of the thoracic spine. Newer MISS approaches to the lumbar spine utilized in the context of lumbar tuberculosis are the MISS Transforaminal lumbar interbody fusion, MISS Extreme lateral lumbar body interbody fusion and the MISS anterior lumbar interbody fusion. The use of endoscopic spinal decompression in the management of infections of the lumbar spine is a relatively new technique and incurs inherently minimal tissue damage. Minimally invasive anterior approaches to the cervical spine are not commonly performed. MISS-microsurgical anterior approach in the context of cervical spine infection have however been reported. MISS posterior approaches to the cervical spine are also being performed. We aimed to provide a review of the MISS approaches currently in use to treat spinal infections to assist spinal surgeons whom manage this problem.

1. Introduction

The last decade has witnessed an exponential growth in the application of minimally invasive surgical approaches to the spine. While spinal surgeons have for decades subjectively appreciated the morbidity of the soft tissue damage associated with the open approaches it was never able to be truly quantified. It is only now through technological advances that allow the minimally invasive approaches to be performed that the true morbidity of the open approaches, through quantitative comparative analysis, have been determined. The application of Minimally invasive spinal surgery (MISS) is new in the treatment of spinal tuberculosis and other spinal infections. Several recent studies have however conclusively shown that MISS, applied to the treatment of spinal infections, demonstrated significant advantages over the open approaches namely less soft tissue damage, less intra-operative blood loss, less post-operative pain, reduced scarring, reduced hospital stay and early return to work [1,2]. The incidence of hematogenous vertebral osteomyelitis is increasing parallel to longer life expectancies, chronic disease, better diagnostic techniques, indwelling intravascular catheters and immunosuppressive therapy [3]. Several studies note vertebral osteomyelitis to constitute between 2% and 7% of all cases of osteomyelitis, over 50% of which occurs in patients older than 50 years [4,6]. With regards patients diagnosed with tuberculosis, spinal involvement occurs in less than 1% [5]. While seemingly a small percentage the increasing overall incidence of the disease in both developed and developing countries makes spinal tuberculosis an important health concern [4,5]. In Sub-saharan African countries the number of reported tuberculosis cases has tripled secondary to the Acquired immunodeficiency syndrome pandemic [6].

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Table 1
Levels of evidence.

I	Large randomized clinical control trials with clear cut results or systematic review of these articles
II	Small randomized clinical control trials with unclear results or systematic reviews of these articles
III	Prospective cohort and case-control studies or systematic reviews of these articles
IV	Historical cohort or case-control studies of systematic reviews of these articles
V	Case series, studies with no controls or Expert opinion

(Adapted from: Sackett DL. *Rules of evidence and clinical recommendations on the use of antithrombotic agents.* Chest 1989; 95:2S–4S).

2. Materials and methods

We conducted a PubMed search using keywords "Minimally invasive spinal surgery spinal infections"; "Minimally invasive spinal surgery spinal tuberculosis"; "Surgery spinal tuberculosis"; "Surgery vertebral osteomyelitis". A paucity of review articles specifically considering MISS surgery for spinal infections was noted, as was an abundance of isolated case reports on the subject. The selection of articles included was subjective based on the discretion of the researchers however favored review articles which specifically concerned minimally invasive spinal surgery performed for spinal infections. We aimed to coalesce several of these review articles and case reports into a specific review of MISS in the context of spinal infections. Our aim is to provide a comprehensive and specific overview of the disease to assist spinal surgeons who manage these patients.

In total 38 articles were selected for inclusion in the review and below are the Study design and Level of evidence for each (Tables 1 and 2).

Table 2
Studies used for this review article by Study type and Level of evidence.

Author (year)	Study design	Level of evidence
Lü G. et al. (2012)	Retrospective cohort	IV
Singh R. et al (2014)	Expert opinion	V
Park K. et al (2014)	Retrospective cohort	IV
Sapico F. et al (1979)	Retrospective cohort	IV
Sai Kiran N. et al (2007)	Retrospective cohort	IV
Rezai A. et al (1995)	Retrospective cohort	IV
Govender S. (2005)	Retrospective systematic review	IV
Leong J. (1993)	Retrospective systematic review	IV
Hendam H. et al (2018)	Retrospective cohort	IV
Venu K. et al (2019)	Retrospective cohort	IV
Vaishya R. et al (2017)	Retrospective systematic review	IV
Ravindra V. et al (2016)	Retrospective cohort	IV
Lü G. et al (2012)	Retrospective cohort	IV
Levin R. et al (2005)	Retrospective cohort	IV
Lee C. et al (2016)	Retrospective case-control	IV
Mamelak A. et al (2008)	Prospective cohort animal study	III
Korkusuz F. et al (1997)	Retrospective cohort	IV
Frykman PK. et al (2013)	Prospective cohort	III
Shirzadi A. et al (2012)	Prospective cohort	III
Vercellino G. et al (2011)	Prospective cohort	III
Foley K. et al (2001)	Retrospective systematic review	IV
Conagee E. et al (1997)	Retrospective cohort	IV
Kandwal P. (2012)	Prospective cohort	III
Ito M. et al (2009)	Retrospective cohort	IV
Kanabar P. et al (2005)	Retrospective systematic review	IV
Moon M (1997)	Retrospective systematic review	IV
Hayashi A (1994)	Retrospective cohort	IV
Meng Y. et al (2019)	Prospective cohort	III
Zaveri G. et al (2009)	Retrospective cohort	IV
Ozgur B. et al (2006)	Retrospective cohort	IV
Gan F. et al (2018)	Retrospective cohort	IV
Pumberger M. et al (2012)	Retrospective cohort	IV
Zhang T. et al (2016)	Retrospective cohort	IV
Obenchain T (1991)	Case report	V
Mac Affee P. et al (1995)	Prospective cohort	III
Muzii V. et al (2006)	Retrospective cohort	IV
Yin X. et al (2018)	Retrospective cohort	IV

3. Results

The diagnosis of spinal infection begins with obtaining a thorough history and performing a clinical examination. Risk factors for the development of spinal infection include advanced age, intravenous drug use, Human immunodeficiency virus infection, chronic use of systemic steroids, diabetes mellitus, immunosuppressive therapy, malnutrition and cancer. Confirmation of the diagnosis is done through hematological and radiological investigations. A raised leucocyte count on full blood count, raised erythrocyte sedimentation rate, and raised C-Reactive protein are highly suggestive of an infective process being present in the body. In the context of acute spinal pain and radiological osseous destruction a raised white cell count and C-reactive protein are suggestive of vertebral osteomyelitis. A more insidious clinical onset, often but not always associated with spinal deformity, and a significantly raised erythrocyte sedimentation rate is suggestive of spinal tuberculosis. In these cases standard radiological investigations include spinal X-Rays, spinal CT scans and MRI spine examinations. Identification of the causative organism is an essential component both for determining a definitive diagnosis as well as establishing antimicrobial sensitivity. This can be achieved by CT-guided biopsy of the affected vertebral body or intervertebral disc. In these cases pre-antimicrobial treatment blood cultures should be done which will be positive in approximately one third of patients with pyogenic vertebral osteomyelitis.

Table of common organisms causing spinal infections [3,4,7]

1	Pyogenic Osteomylitis	Stapylococcous aureus Steptococcus species Escherichia Coli Proteus species Pseudomonas Salmonella
2	Tuberclous infection	Mycobacterium tuberculosis Mycobacterium avium intra-cellulare
3	Fungal infection	Candida species Cryptococcus neoformans Aspergillus species
4	Parasitic infection	Echinococcus granulosus Toxoplasma gondii Taenia solium
5	Post-operative surgical site infection	Staphylococcus aureus Staphylococcus epidermidis
6	Infections in the immune-compromised	Pseudomonas aeruginosa Escherichia coli

4. Surgical treatment

The indications for surgical intervention in spinal infections are 1. Significant bony destruction causing instability; 2. A significantly sized *para*-vertebral abscess where anti-microbial penetration is poor; 3. Progressive neurology secondary to compression; 4. An unacceptable deformity for example kyphosis > 20 degrees or listhesis; 5. Septic pseudarthrosis and 6. Failure to respond to 6–8 weeks of medical management [8,9]. The goal of MISS is to reach the affected target

through as minimal a surgical corridor as necessary and in so doing reduce iatrogenic trauma to the surrounding tissues. In so doing the approach-related morbidity of the surgery is minimized leading to improved and earlier clinical recovery.

5. Thoracic spinal infections

In the thoracic spine the 1. Exact site of the focus of infection and the 2. Extent of kyphosis determines the ideal surgical approach. Posterior epidural abscesses causing significant cord compression may for example be addressed with a simple posterior approach through a tubular retractor. More extensive spinal infections with osseous destruction largely involve the vertebral bodies and hence once significant vertebral body destruction and significant kyphosis develop an anterior approach is ideal to address these problems by performing a direct anterior debridement and reconstruction. The level of the pathology is a further consideration determining the appropriate surgical approach. Tuberculosis infection in the upper thoracic levels (T1-T4) for example is best addressed through a mini-posterior costotransversectomy. In comparison tuberculosis at the mid-thoracic level (T5-T10) level is best addressed through a mini-thoracotomy or the newer Video-assisted thoracoscopic surgery (VATS). By further comparison neither of these approaches is ideally suitable for tuberculosis of the thoracolumbar junction (T12-L1). Here a thoracolumbar approach must be used and for this purpose a mini-open thoraco-abdominal approach or the newer Video-assisted thoracoscopic surgery (VITOM) mini-thoracotomy approach can be utilized. In the thoracic spine the specific infective indications for MISS are progressive neurological deficit secondary to spinal cord compression, a significantly pre or para vertebral abscess collection, post-infective thoracic disc herniation, post-infective thoracic spinal stenosis and significant post-infective kyphotic deformity. Contraindications to utilizing MISS in the thoracic spine are extensive scarring and adhesions from previous thoracotomy, respiratory insufficiency secondary to thoracic empyema, pleurodesis, or bullous lung pathology and a narrow anteroposterior chest diameter which limits the working space. The following MISS approaches to the thoracic spine are utilized according to the literature reviewed 1. Mini-thoracotomy; 2. Mini-open thoracoscopically assisted thoracotomy (MOTA); 3. Video-assisted thoracoscopic surgery (VATS); 4. Video assisted telescopic operating microscope assisted thoracotomy (VITOM thoracotomy); and 5. Percutaneous thoracic fixation.

5.1. Mini-thoracotomy

A mini-thoracotomy is a variant of the traditional open thoracotomy which aims to avoid the significant morbidity of performing the traditional open approach. The advantages over the former are that with a mini-thoracotomy the incision is significantly smaller. This translates into less muscle damage by reducing the length of intercostal muscle transected which leads to less post-operative pain and patients report an earlier return to work. The disadvantages over the mini-thoracotomy are difficulty in combining visualization and working into a single small channel and hence in in the authors experience, regarding his own practice, two mini-thoracotomies are often necessary, one for visualization and another for working. Further disadvantages are prolonged operating times, increased radiation exposure, less surface area of bone exposed for fusion cases, difficulty repairing a cerebrospinal fluid leak if one occurs and the steep learning curve with increased complications reported in several series. Despite these limitations several series report satisfactory outcomes in the treatment of spinal infections with this technique [10,11].

5.2. Mini-open thoracoscopically assisted thoracotomy (MOTA)

The MOTA is a hybrid approach that combines the advantages of the superior visualization afforded by the thoracoscope but retains the superior access afforded by a mini-thoracotomy. In this procedure a single mini-thoracotomy is performed which becomes purely a working channel. Thereafter the thoracoscope is introduced into the pleural space through a separate anterolateral thoracoscopic incision to assist visualization. Several papers report the success of MOTA in the treatment of spinal infections [12,13].

5.3. Video-assisted thoracoscopic surgery (VATS)

The video-assisted thoracoscopic technique is a further advancement of MISS by avoiding the morbidity of a mini-thoracotomy altogether. This technique involves the use of an endoscopic camera and light source introduced through a 2–3 cm visualization portal and the subsequent introduction of a 2–3 cm retraction portal and a 2–3 cm additional working portal. Additional 2–3 cm working portals may be added in multi-level disease. These portals are mere stab incisions through the chest wall and hence allow visualization, retraction as well as working access. Several papers report the success of VATS to treat spinal infections and note the significant benefit of avoiding the morbidity of a mini-thoracotomy in terms of a reduction in chest wall pain and earlier return to function [12,14,15].

In the mini-thoracotomy, MOTA, and VATS technique the patient is afforded a general anesthesia and single lung ventilation is employed using a double-lumen endotracheal tube. In most cases, taken from the authors experience, complete deflation of the lung on the operative side is required. The anaesthetized patient is placed in the lateral decubitus position [Fig. 1]. In the mini-thoracotomy and MOTA techniques the attending spinal surgeon then makes his/her mini-thoracotomy incision after utilizing fluoroscopic imaging to confirm the level. A typical mini-thoracotomy skin incision is 7 cm in length. The incision is typically oblique from cephalad-posterior to caudal-anterior which allows access to multiple ribs and several vertebral levels through a single working channel. Minimal dissection is carried out through the latissimus dorsi and serratus anterior muscles. In the mini-thoracotomy this single channel functions to provide direct visualization as well as for working which in the authors experience is difficult. In the MOTA technique the mini-thoracotomy is purely a working channel and an additional anterolateral 1.5 cm incision is created for introduction of the thoracoscope to assist visualization [Fig. 2]. In the VATS technique no mini-thoracotomy is performed and instead several small 2–3 cm thoracoscopic portals [Fig. 3] are used [12–14].

The thoracoscope, whether placed through an additional anterolateral incision as in MOTA, or through a 2–3 cm portal as in VATS, significantly improves visualization within the pleural space. The disadvantage of MOTA and VATS, by both utilizing an endoscope placed within the pleural space close to the operating field, is frequent clouding of the lens which needs to be repeatedly cleaned. In the mini-thoracotomy and MOTA techniques drainage of the pre-vertebral abscess and the subsequent necrotic vertebral body debridement is completed from an antero-lateral approach through the mini-thoracoscopic

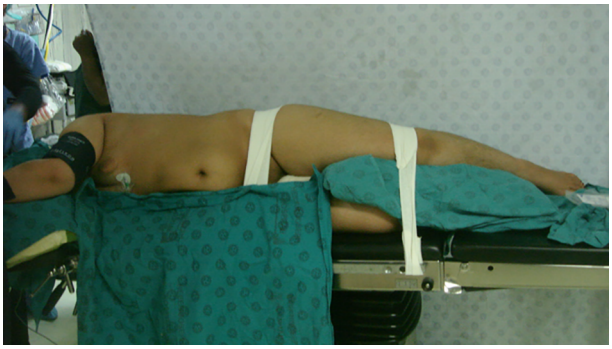


Fig. 1. Intra-operative photograph showing lateral decubitus position of the patient in the MISS approach to the thoracic spine.



Fig. 2. Intra-operative photograph showing mini-thoracotomy and separate anterolateral incision for the thoracoscope in MOTA.

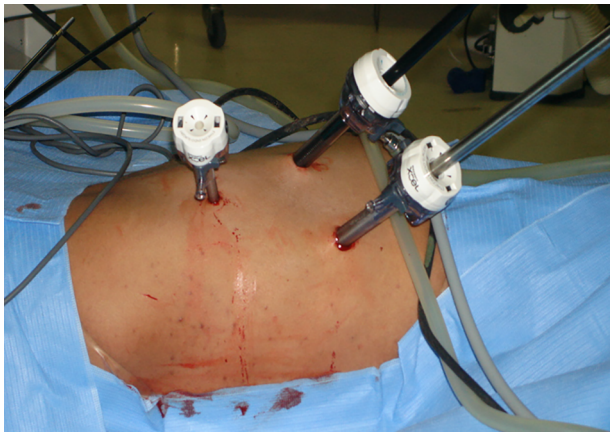


Fig. 3. Intra-operative photograph showing the classical three portals used in VATS.

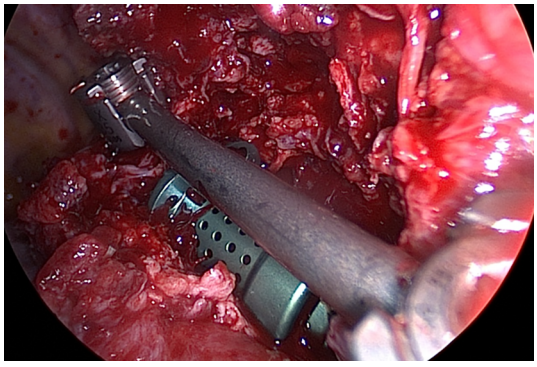


Fig. 4. Intra-operative photograph showing the thoracoscopic anterior re-construction in VATS.

working channel. Rib head resection can also be performed if necessary. In VATS the debridement and reconstruction are all performed through one or several 2–3 cm thoracoscopic working portals. There are specific instruments which are required specific to these techniques such as thoracotomy retractors and rib approximators in the mini-thoracotomy and MOTA, and thoracoscopic lung retractors in VATS. Long Cobb dissectors, long osteotomes, long diathermy tips are more standard and are utilized in all three approaches. In certain cases an intercostal drain may be required. It is important to use a radiolucent table as at any point fluoroscopic confirmation may be needed. Once the debridement is completed the spinal column re-construction is performed [Fig. 4], the surgical incisions are closed in layers. In the mini-thoracotomy and MOTA the mini-thoracotomy scar is relatively small and is hidden in the mid-axillary line. In VATS several, usually three, small scars on the chest wall are all that testify to the surgery having been performed [12–17].

While in pyogenic spinal infections an autologous bone grafting for anterior column re-construction utilizing autologous resected rib has traditionally been favored this is discouraged in long segment disease in the thoracic spine due to a high failure rate. A fibular graft or tri-cortical iliac crest graft is noted to offer superior stability. The benefits of tuberculosis not forming a biofilm on titanium implants enables these to be used for robust support. Long segment gaps are ideal for the utilization of these implants and both mesh and self-expanding cages are being used. These implants are filled with bone graft and thereby become osseo-conductive and osseo-inductive for immediate integrative osteogenesis [18].

5.4. Video-assisted telescopic operating microscope mini-thoracotomy (VITOM)

VITOM mini-thoracotomy is a fairly novel technique. This *exo*-scope comprises an 8-mm diameter rigid lens telescope with a scope holder that permits repositioning. The telescope is attached to a digital camera and then to a monitor. The Video telescope operating microscope provides 2–16 times magnification zoom and illumination, and by being outside of the surgical field does not occupy space within the mini-thoracotomy working channel. Additional benefits of the exoscope is that clouding of the lens, as occurs during MOTA and VATS, does not occur [Figs. 5, 6]. Several studies report the advantages of VITOM over the endoscope and the microscope [18–21].

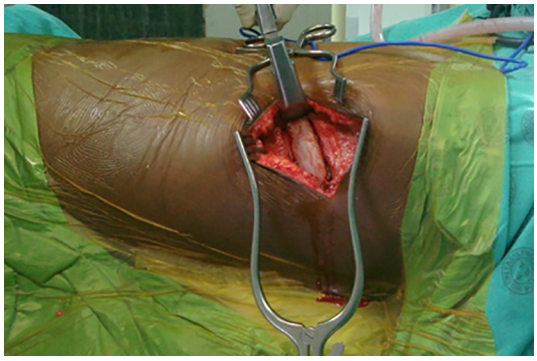


Fig. 5. Intra-operative photograph showing the mini-thoracotomy performed for VITOM with exposure of the rib.



Fig. 6. Intra-operative photograph showing the VITOM exoscope being used to assist visualization. Here it is being used with a MISS-tubular retractor system in the lumbar spine.

The relative differences among mini-thoracotomy, MOTA, VATS and VITOM thoracotomy in the authors experience:

	Mini-thoracotomy	MOTA	VATS	VITOM
Exposure and access	Difficult visualization and working through a single relatively small channel. In the authors experience a double mini-thoracotomy for multi-level disease is often required.	Exposure limited by small mini-thoracotomy incision which is purely a working channel. Visualization enhanced by separate anterolateral thoracoscopic illumination	Exposure, retraction and visualization are afforded through three separate 2–3 cm thoracoscopic portals. Multi-level disease can be addressed by sequential addition of cranial and caudal working portals	Exposure and visualization through a single channel. Exoscope does not occupy space in the working channel and clouding of the lens is avoided
Equipment and assistant	Standard	Thoracoscope, standard instruments	Thoracoscope, thoracoscopic retractors, thoracoscopic instruments	VITOM *exo*-scope, Standard instruments
Incision and cosmesis	7 cm, hidden in mid-axillary line	Small, easy to conceal	Multiple small 2–3 cm incisions mostly contained within the axilla	Smaller incision than mini-thoracotomy
Muscle dissection	Limited muscle dissection	Limited muscle dissection	Minimal muscle dissection	Limited muscle dissection
Operative time	Equivalent to MOTA	Equivalent to mini-thoracotomy	Increased overall.	Equivalent to MOTA and mini-thoracotomy
Blood loss	High	Moderate	Low	Low
Hemostasis	Relatively easy proximal and distal control in case of major bleeding	Incision can easily be extended to allow proximal control in case of major bleeding	May need to convert to open thoracotomy	May need to convert to open thoracotomy
Single lung Ventilation	Rarely required	Rarely required	Always required when patient in lateral decubitus position. Not required in prone positioning	Rarely required
Hospital stay	4 to 6 days	4 to 6 days	4 to 6 days	4 to 6 days

5.5. Percutaneous thoracic fixation

Posterior percutaneous pedicle screw fixation is an additional option affording dynamic stabilization in the thoracic spine [Figs. 7, 8]. Decompression of the spinal cord and thecal sac is usually done via a laminotomy or laminectomy using the tubular retractor system which can be re-directed to perform a mini-costotransversectomy for the drainage of pus from the paravertebral space. The role of percutaneous pedicle screw fixation is to offer a minimally invasive adjunct when concerns over the stability of a significant infectious wedge compression fracture, or minimally burst infective fracture without significant anterior cord compression, exist [22,23]. In gross vertebral body destruction with significant kyphosis or anterior thecal sac compression this method is not suitable and an anterior approach is more suitable with direct thecal sac decompression and anterior column reconstruction. Several papers recommend percutaneous pedicle screw fixation in multi-segmental spinal spinal tuberculosis with instability [24,25].

5.6. Lumbar spinal infections

Regarding infections of the lumbar spine neurological complications are uncommon as compared to infection of the thoracic spine. In those patients presenting with neurology paraplegia is the most common presenting symptom. Lesions at or above L1 classically present as a myelopathy while below that nerve root symptoms predominate [26].

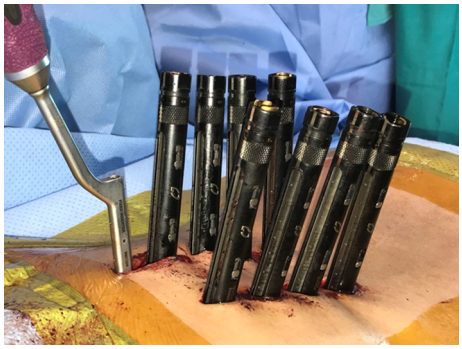


Fig. 7. Intra-operative photograph of a MISS percutaneous spinal fixation technique being performed.

Surgery is reserved for patients presenting with progressive neurology or deformity [27]. Here decompression of neural elements, correction of deformity, and bone grafting should be considered together as the aim of surgery. The significant axial loading in the lumbar spine makes devascularized autologous rib grafting unsuitable and again a fibular graft or tri-cortical iliac crest graft offers superior stability. In centers with expertise in performing the procedure a vascularized iliac bone graft supplied by the first or second lumbar segmental vessel is the autologous graft of choice [32]. With regards tuberculosis of the lumbar spine the MISS anterior; anterolateral; lateral *trans*-psoas utilizing a tubular retractor system with neuro-monitoring to avert injury to the lumbo-sacral plexus, and posterolateral *trans*-pedicular approaches again utilizing a tubular retractor [Fig. 9] are well described [26–28].

Newer MISS approaches to the lumbar spine utilized in the context of lumbar tuberculosis are the MISS Transforaminal lumbar interbody fusion (MISS-TLIF), MISS Extreme lateral lumbar body interbody fusion (MISS-XLIF) and the MISS anterior lumbar interbody fusion (MISS-ALIF). In the MISS-TLIF technique the spinal surgeon reaches the

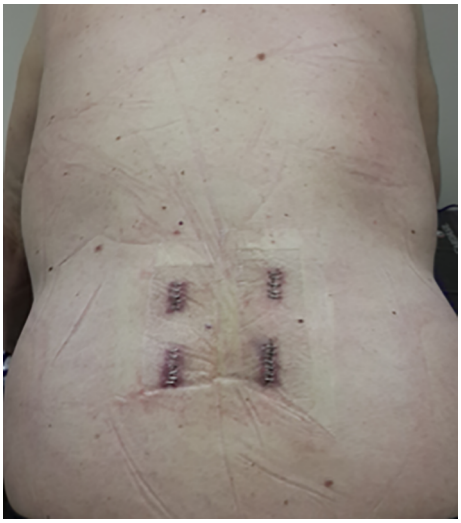


Fig. 8. Patient photograph of surgical incisions post single level MISS percutaneous spinal fixation.

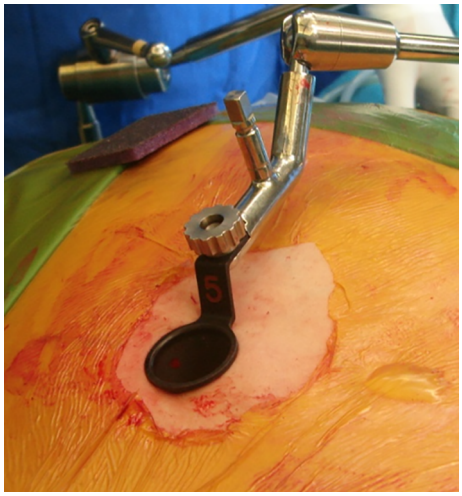


Fig. 9. intra-operative photograph of the MISS tubular retractor system.



Fig. 10. Patient photograph showing the surgical scar post endoscopic lumbar discectomy.

lumbar intervertebral disc space through a 2 cm paramedian incision with a muscle spilt between the multifidus and longissimus muscles and uses the tubular retractor to reach the facet Joint which is resected to reach the disc space for debridement. In inherent destabilizing effect of the facetectomy necessitates pedicle screw and rod placement. Several papers report the success of the MISS-TLIF technique in the management of tuberculous infection of the lumbar spine to correct lumbar lordosis in the context of disc space collapse [29,30]. The MISS-XLIF is a minimally invasive *trans*-psoas approach for lateral interbody fusion. This approach is used as an alternative to the MISS-ALIF. MISS-XLIF is used as minimally invasive approach which has the advantage of sparing the anterior longitudinal ligament while still allowing direct visualization of the intervertebral discs and bodies for debridement and placement of a large, lordotic cage in lumbar tuberculous infection. XLIF has also been used in pyogenic lumbar vertebral osteomyelitis. One paper reports MISS-XLIF to offer great advantages which include less a smaller incision, less tissue damage, decreased operation time, less blood loss, shorter hospital stays, and reduced postoperative pain in vertebral osteomyelitis cases. Contraindications to performing the technique noted are a severely destroyed vertebral body with loss of more than 40% of vertebral body height, significant deformity namely a Cobb angle of greater than 30 degrees in the sagittal or coronal plane, multi-level disease, and a large collection of purulent material [31]. Another paper reports the success of the technique in restoring lordosis in lumbar tuberculosis [32]. The technique is however not without complications and these include lower limb sensory deficits and mechanical psoas muscle weakness although the incidence of these is low if neuro-monitoring is used [33]. Due to its high complication rate, which includes a significant risk of retrograde ejaculation in males post injury to the sacral plexus, the MISS-ALIF is largely reserved for infection of the L5/S1 disc space where a MISS-XLIF is not possible due to interference of the iliac crests in the surgical corridor. The MISS-TLIF is a safer option here and is the preferred option [34].

The use of endoscopic spinal decompression in the management of infections of the lumbar spine is a relatively new technique and incurs inherently minimal tissue damage and less post-operative scarring [Fig. 10]. The procedure is however technically demanding and has therefore been slow to gain popularity. The posterolateral endoscopic approach is a treatment option in experienced hands especially suited for patients with a poor general condition due to serious co-morbid medical problems making them unsuitable for an open procedure. The endoscopic approach is best indicated in the early phase of a fungal, bacterial or tuberculosis infection. In chronic cases the pus or the infected disc becomes hard and is difficult to remove through the endoscope. The contra-indication for the endoscopic procedure are spinal infections with severe destructive changes of the vertebral body which need major debridement or a corpectomy to be performed. The use of the endoscopic has been reported useful in the decompression of paraspinal abscesses and in the debridement of necrosis in the lumbar region [35,36].

5.7. Tuberculosis of the cervical spine

Minimally invasive anterior approaches to the cervical spine are not commonly performed as the procedure is technically difficult in the context of treating cervical spine infections. With regards the development of an anterior epidural abscess the clinical presentation usually begins with severe, rapidly worsening, neck pain radiating to the interscapular region or upper limb. One paper reports the successful use of a MISS- microsurgical anterior approach in the context of cervical spine infection to perform a single level discectomy with curettage of the disc plates at the level of the discitis. This same paper reports the contraindications to the procedure namely acute kyphotic angulation of greater than 20 degrees and loss of greater than 50% of vertebral body height [37]. Another MISS surgical option is an anterior endoscopic cervical discectomy however in the context of cervical spinal infections thick pus and caseous material make this technically difficult [28]. MISS posterior approaches to the cervical spine are performed through a tubular retractor system to address specific issues such as performing a laminectomy to drain a posterior epidural abscess causing cord cpompression. There is no percutaneous lateral mass screw system currently available and if posterior stabilization is needed an open procedure is better suited [38].

6. Conclusion

Minimally invasive spine surgery in the context of treating thoracic spinal infections is clearly well established. These procedures are furthermore gaining popularity in the lumbar spine and remain rarely performed in the cervical spine. Spinal surgeons need a special skill set to perform these procedures and they should not be performed by novice surgeons. The steep learning curve is formidable and is although regarded as unacceptable by some this not seen a dampening of their application. As spinal infections increase in incidence so to will papers reporting the use of MISS techniques applied to their management.

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Conflicts of interest statement

None of the authors listed below have any financial nor personal relationships with other people, or organizations, that could inappropriately influence (bias) their work, all within 3 years of the beginning the work submitted.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2020.100749.

References

[1] G. Lü, B. Wang, J. Li, W. Liu, I. Cheng, Anterior debridement and reconstruction via thoracoscopy assisted mini-open approach for the treatment of thoracic spinal tuberculosis: minimum 5 year follow-up, Eur. Spine J. 21 (2012) 463–469.

[2] R. Singh, P. Gogna, S. Parshad, P. Karwasra, K. Kaur, Video-assisted Thoracic surgery for Tubercular Spondylitis Minimally Invasive Surgery, 2014. Article ID 963497:1-8.

[3] K.H. Park, O.H. Cho, M. Jung, K.S. Suk, J.H. Lee, et al., Clinical characteristics and outcomes of hematogenous vertebral osteo-myelitis caused by gram negative bacteria, J. Infect. 69 (2014) 42–50.

[4] F.L. Sapico, J.Z. Montgomerie, F.L. Sapico, J.Z. Montgomerie, Pyogenic vertebral osteomyelitis: report of nine cases and review of the literature, Clin. Infect. Dis. 1 (1979) 754–776.

[5] N.A. Sai Kiran, S. Vaishya, S.S. Kale, B.S. Sharma, A.K. Mahapatra, Surgical results in patients with tuberculosis of the spine and severe lower-extremity motor deficits: a retrospective study of 48 patients, J. Neurosurg. Spine 6 (2007) 320–326.

[6] A.R. Rezai, M. Lee, P.R. Cooper, T.J. Errico, M. Koslow, Modern management of spinal tuberculosis, Neurosurgery 36 (1995) 87–97.

[7] Fourteenth report of the Medical Research Council Working Party on Tuberculosis of the Spine, Five-year assessment of controlled trials of short-course chemotherapy regimens of 6,9 or18 months duration for spinal tuberculosis in patients ambulatory from the start or undergoing radical surgery, Int. Orthop. 23 (2) (1999) 73–81.

[8] S. Govender, Spinal infections, J. Bone Surg. Br. 87 (2005) 1454–1458.

[9] J. Leong, Tuberculosis of the spine, J. Bone Joint Surg. Br. 75 (2) (1993) 173–175.

[10] H. Hendam, H. El-Samouly, H. Behairy, M. Noaman, G. Elshafy, Mini thoracotomy approach to upper thoracic spine, J. Scientific Res. 9 (1) (2018) 1–5, https://doi.org/10.4236/nm.2018.91002.

[11] K. Venu, J. O'Dowd, Mini-thoracotomy provides satisfactory access for anterior release for spinal deformity correction and fusion, Orthop. Proc. 84-B (SUPP III) (2019).

[12] R. Vaishya, V. Vijay, A. Agarwal, Video-assisted thoracoscopic surgery for drainage of dorsal paravertebral abscess, Arthrosc. Techniques 6 (4) (2017) e1137–e1143.

[13] V. Ravindra, A. Brock, A. Awad, R. Kalra, M. Schmidt, The role of the mini-open thoracoscopic-assisted approach in the management of metastatic spine disease at the thoracolumbar junction, Neurosurg. Focus. 41 (2) (2016) E16.

[14] G. Lü, B. Wang, J. Li, W. Liu, I. Cheng, Anterior debridement and reconstruction via thoracoscopy-assisted mini-open approach for the treatment of thoracic spinal tuberculosis: minimum 5-year follow-up, Eur. Spine J. 21 (3) (2012) 463–469.

[15] R. Levin, D. Matusz, A. Hasharoni, C. Schaarf, B. Lonner, T. Errico, Mini-open thoracoscopically assisted thoracotomy versus video-assisted thoracoscopic surgery for anterior release in thoracic scoliosis and kyphosis: A comparison of operative and radiographic results, Spine J. 5 (6) (2005) 632–638.

[16] C. Lee, M. Wu, Y. Li, C. Cheng, C. Lee, T. Huang, Video-assisted thoracoscopic surgery and minimal access spinal surgery compared in anterior thoracic or thoracolumbar junctional spinal reconstruction: a case-control study and review of the literature, Biomed. Res. Int. (2016) 6808507, https://doi.org/10.1155/2016/6808507.

[17] A. Mamelak, M. Danielpour, K. Black, G. Berci, A high-definition exoscope system for neurosurgery and other microsurgical disciplines: preliminary report, Surg. Innov. 15 (1) (2008) pp. 38–46.

[18] F. Korkusuz, C. Islam, Z. Korkusuz, Prevention of postoperative late kyphosis in Pott's disease by anterior decompression and intervertebral grafting, World J. Surg. 21 (5) (1997) 524–528.

[19] P.K. Frykman, B.P. Duel, A. Gangi, J.A. Williams, G. Berci, A.L. Freedman, Evaluation of a video telescopic operating microscope (VITOM) for pediatric surgery and urology: a preliminary report, J. Laparoendosc. Adv. Surg. Tech. A. 23 (7) (2013) 639–643.

[20] A. Shirzadi, D. Mukherjee, D.G. Drazin, et al., Use of the video telescope operating monitor (VITOM) as an alternative to the operating microscope in spine surgery, Spine 37 (2012) E1517–E1523.

[21] G.F. Vercellino, E. Erdemoglu, S. Kyeyamwa, et al., Evaluation of the VITOM in digital high-definition video exocolposcopy, J. Lower Genit. Tract. Dis. 15 (2011) 292–295.

[22] K.T. Foley, S.K. Gupta, J.R. Justis, et al., Percutaneous pedicle screw fixation of the lumbar spine, Neurosurg. Focus 10 (2001) E10.

[23] E.J. Conagee, Instrumentation of the infected and unstable spine. A review of 17 cases from the thoracic and lumber spine with pyogenic infections, J. Spinal Disorder. 10 (1997) 317–324.

[24] P. Kandwal, B. Garg, B. Upendra, B. Chowdhury, A. Jayaswal, Outcome of minimally invasive surgery in the management of tuberculous spondylitis, Indian J. Orthop. 46 (2) (2012) 159–164, https://doi.org/10.4103/0019-5413.93680.

[25] M. Ito, H. Sudo, K. Abumi, Y. Kotani, M. Takahata, M. Fujita, et al., Minimally invasive surgical treatment for tuberculous spondylodiscitis, Minim. Invasive Neurosurg. 52 (5–6) (2009) 250–253, https://doi.org/10.1055/s-0029-1220685.

[26] P. Kanabar, Tuberculosis of lumbar spine, Indian J. Orthop. 39 (2005) 81–89.

[27] M.S. Moon, Tuberculosis of the spine. Controversies and a new challenge, Spine 22 (15) (1997) 1791–1797.

[28] A. Hayashi, Y. Maruyama, Y. Okajima, M. Motegi, Vascularized iliac bone graft based on a pedicle of upper lumbar vessels for anterior fusion of the thoraco-lumbar spine, Br. J. Plast. Surg. 47 (6) (1994) 425–430.

[29] Y. Meng, Y. Hang, D. Hao, S. Jia, X. He, D. Liu, L. Sun, Application of transforaminal-lumbar interbody fusion technology combined with lesion clearance and chemotherapy via catheter for the treatment of spinal tuberculosis, Exp. Ther. Med. 18 (1) (2019) 57–62, https://doi.org/10.3892/etm.2019.7536.

[30] G. Zaveri, Surgical treatment of lumbar tuberculous spondylodiscitis by transforaminal lumbar interbody fusion (TLIF) and posterior instrumentation, J. Spinal Disorders Tech. 22 (4) (2009) 257–262.

[31] B.M. Ozgur, H.E. Aryan, L. Pimenta, et al., Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion, Spine J. 6 (2006) 435–443.

[32] F. Gan, J. Jiang, Z. Xie, S. Huang, Y. Li, G. Chen, H. Tan, Minimally invasive direct lateral interbody fusion in the treatment of the thoracic and lumbar spinal tuberculosis, BMC Musculoskeletal Disord. 283 (2018), https://doi.org/10.1186/s12891-018-2187-3.

[33] M. Pumberger, A. Hughes, R. Huang, A. Sama, F. Cammisa, F. Girardi, Neurologic deficit following lateral lumbar interbody fusion, Eur. Spine J. 21 (6) (2012) 1192–1199.

[34] T. Zhang, X. He, X. Li, S. Xu, Treatment of lumbosacral spinal tuberculosis by one-stage anterior debridement and fusion combined with dual screw-rod anterior instrumentation underneath the iliac vessel, BMC Musculoskelet Disord. 17 (2016) 49, https://doi.org/10.1186/s12891-016-0902-5.

[35] T.G. Obenchain, Laparoscopic lumbar discectomy: case report, J. Laparoendosc. Surg. 1 (1991) 145–149.

[36] P.C. MacAffee, J.J. Regan, T. Zdeblick, The incidence of complications in endoscopic anterior thoracolumbar spinal reconstructive surgery. A prospective multicenter study comprising the first 100 consecutive cases, Spine 20 (1995) 1624–1632.

[37] V.F. Muzii, A. Mariottini, A. Zalaffi, B.R. Carangelo, L. Palma, Cervical spine epidural abscess: experience with microsurgical treatment in eight cases, J. Neurosurg. Spine 5 (2006) 392–397.

[38] X. Yin, B. He, Z. Liu, D. Hao, The clinical outcomes and surgical strategy for cervical spine tuberculosis A retrospective study in 78 cases, Medicine (Baltimore) 97 (27) (2018) e11401, https://doi.org/10.1097/MD.0000000000011401.