In the last five years, surgeons have applied endoscopic transforaminal surgical techniques mastered in the lumbar spine to the treatment of thoracic pathology.

The aim of this systematic review was to collate the available literature to determine the place and efficacy of full endoscopic approaches used in the treatment of thoracic disc prolapse and stenosis.

An electronic literature search of PubMed, Embase, the Cochrane database and Google Scholar was performed as suggested by the Preferred Reporting Items for Systematic Review and Meta-analysis statements. Included were any full-text articles referring to full endoscopic thoracic surgical procedures in any language.

We identified 17 patient series, one cohort study and 13 case reports with single or of up to three patients.

Although the majority included disc pathology, 11 papers related cord compression in a proportion of cases to ossification of the ligamentum flavum or posterior longitudinal ligament. Two studies described the treatment of discitis and one reported the use of endoscopy for tumour resection.

Where reported, excellent or good outcomes were achieved for full endoscopic procedures in a mean of 81% of patients (range 46–100%) with a complication rate of 8% (range 0–15%), comparing favourably with rates reported after open discectomy (anterior, posterolateral and thoracoscopic) or by endoscopic tubular assisted approaches. Twenty-one of the 31 author groups reported use of local anaesthesia plus sedation rather than general anaesthesia, providing ‘self-neuromonitoring’ by allowing patients to respond to cord and/or nerve stimuli.

Keywords: full endoscopic; thoracic discectomy; transforaminal surgery

Introduction

It is well recognized by surgeons that interventional treatments at the thoracic level are liable to be technically difficult and demanding. Not only is surgical access to the thoracic spinal canal limited by the anatomical constraints of the rib attachments but the spinal cord at the thoracic level is particularly vulnerable to surgical intervention. The natural thoracic kyphosis flattens the dural sheath against the posterior margin of the disc and the spinal cord’s mobility is limited within the canal by the denticulate ligaments. In addition, the ratio of cord diameter to that of the canal leaves little space around the cord and, at some levels, the medullary vascularization is limited.1

In the majority of world centres, thoracic disc pathology is still approached using direct open anterior or posterior approaches.2 Direct access via a transthoracic approach3 entails opening the chest cavity and, in the case of a disc prolapse, excision of significant healthy tissue before reaching the protruding fragment. Advocated for central calcified discs, the quantity of bone and disc resection will generally require vertebral fusion to prevent postoperative pain at the affected level. Even with a more minimal approach using video-assisted thoracoscopic techniques (VATS),4,5 or mini-thoracotomy (mini TTA),6 there remains a significant risk of complications including paralysis, paresis, pleural tear and pneumothorax.7,8 The alternative direct posterior approaches with laminotomy and durotomy are similarly disliked by most surgeons as segmental nerve root resection will generally require vertebral fusion to prevent postoperative pain at the affected level. Even with a more minimal approach using video-assisted thoracoscopic techniques (VATS),4,5 or mini-thoracotomy (mini TTA),6 there remains a significant risk of complications including paralysis, paresis, pleural tear and pneumothorax.7,8 The alternative direct posterior approaches with laminotomy and durotomy are similarly disliked by most surgeons as segmental nerve root resection may be required and the risk of cord injury is significant.9 This leaves one of the posterolateral approaches as probably the most commonly performed choice of access to the spine, including costo-transversectomy, transpedicular and lateral extracavitary techniques.10–12 Unfortunately, in each approach, rib head or pedicular resections are required, leading potentially to intraoperative entry to the chest and postoperative pain. Access to the central areas of the disc is also limited. Overall, complications from open surgery are reported to...
occur in excess of 25% of patients\cite{7,13} and, for this reason, approaches minimizing operative harm are ideal.

As a separate entity from disc prolapse, spinal stenosis is relatively rare in the thoracic spine and generally occurs below the T9 vertebra. When it does occur, the stenosis is often severe and decompression is urgent as cord compromise may lead to myelopathy. Traditionally, as in the lumbar spine, a laminectomy would be offered, but surgeons have long recognized that this is associated with a significant risk of the development of postoperative kyphosis. Also, if there is associated ossification of the posterior longitudinal ligament, a thoracotomy will be required or macro-invasive circumferential decompression.\cite{14-16} Although some attempts have been made to reduce ‘invasion’ by tubular decompression through large bore cannulae, these techniques have not been universally adopted.\cite{17}

In the 1980s, surgeons recognized the potential for safe access to the spine via the Kambin triangle,\cite{18} and this led to the development of full endoscopic instrumentation that could be coupled to high-definition video camera systems. Although initially the primary focus was on access to the lumbar spine,\cite{19} there are now state of the art instruments suitable for use in both the neck and thoracic regions (Fig. 1).

Following initial technical notes,\cite{20-22} there have been an increasing number of publications describing the use of full endoscopy applied to thoracic pathology and it is now timely to review the substantive evidence supporting the novel techniques described. The aims of this review are therefore to describe the most frequently adopted transforaminal and interlaminar endoscopic approaches and collate the evidence for and against the techniques and advances in technology described, contrasting outcome data with those expected after open surgery. The following full endoscopic classifications are currently recommended by the AO Spine group.\cite{23}

1) Transforaminal endoscopic thoracic discectomy (TETD).
2) Thoracic endoscopic unilateral laminotomy for bilateral decompression (TE-ULBD).
3) Transpedicular endoscopic surgery.

**Approaches and differences in full endoscopic thoracic techniques**

Most commonly, either a transforaminal or interlaminar approach will be used for endoscopic access (Fig. 2).

**Transforaminal technique**

The anatomy at the levels T2 to T9 differs from that at the thoraco-lumbar junction due to the overlap of the rib heads, which cover approximately half of the foraminal and disc space (Fig. 3). A partial resection of the rib heads during endoscopic surgery is therefore required. At the thoracolumbar region, the anatomy is very similar to that of the lumbar spine, although careful preoperative evaluation of the retroperitoneal area should be performed to avoid approach-related complications with injury to a kidney or bowel. Optimally the patient is positioned prone with an approach from the side of main clinical symptoms and spinal pathology. The ribs are palpated through...
the skin and an incision made about 5 cm lateral to the spinous process line. The angle of the access needle is 20–30 degrees in a cranio-caudal direction pointing to the lateral recess and the caudal part of the neuroforamen of the symptomatic level.

The fragility of the thoracic neural structures limits the placement of the approach tools and initial aim of these should be towards the disc. A Jamshidi needle, or pointed approach rod, is a helpful aid with puncture of the cranial part of the rib head and advancement into the disc space. Discography with methylene blue or indigo carmine is then possible and helpful to differentiate disc from other tissues. In rare cases with sequestred disc material a transpedicular approach may be appropriate.

As a consequence of the thoracic foraminal anatomy and the relatively small size of the neuroforamina, a diamond burr should be used intraoperatively under endoscopic visual control to widen out the working space. After placing the endoscope, the epidural space, disc and lateral recess are identified. This is followed by a stepwise preparation and enlargement of the foraminal area with the aim of creating space for the endoscope and gaining mobility inside the spinal canal (Fig. 4). The next step is to identify the ventral bone structures as well as the margins of the disc. Under endoscopic view, bone and disc material are removed and anterior decompression achieved (Fig. 5). A flexible bipolar radiofrequency probe is useful to stop any epidural bleeding. After decompression and visual inspection of the decompressed nerve elements, repeatedly checking positioning with the endoscope and image intensifier, the endoscope may be removed and skin closed.

**Interlaminar technique**

The main differences between the interlaminar approach at the thoracic to that at lumbar levels relate to the lesser size and thickness of the laminae, the more horizontal anatomical orientation of the facet joints and the fragility of the neural structures. The thickness of the flaval ligament increases stepwise from the upper to the lower spine and the architecture limits interlaminar endoscopic techniques for posterior and lateral pathologies. Similar to open techniques, a medial pedicle resection is necessary to create enough space to avoid manipulation of the central cord.

For the posterior decompression procedures without disc resection, a large diameter endoscope (e.g. Ilessys Delta®, joimax GmbH or Vertebris stenosis®, RIWOpine GmbH) will allow a controlled resection of posterior compressive structures. Close attention is necessary as the decompressed area of the interlaminar window must not exceed the size of the working tube to avoid an uncontrolled antero-posterior movement and manipulation of the dura with potential tear. A holding arm is helpful to avoid uncontrolled pressure on the cord.

Patients are best positioned prone. The incision is about 3 cm from the midline unless contralateral decompression is needed, in which case 5 cm may be more appropriate. After stepwise dilatation the endoscope is inserted. The laminae and interlaminar window are decompressed with a combination of a diamond burr and Kerrison punches.
In bilateral stenotic pathologies the ipsilateral side should be decompressed and then the contralateral side, using an ‘over-the-top’ technique. All areas of the spine may be reached (Fig. 6). If possible, the ligamentum flavum should be maintained intact until the bone decompression has been finished as it is used as a protection of the dura. After decompression, a radiograph will confirm the amount of decompression achieved. Anterior pathologies of the lateral recess may be addressed by interlaminar endoscopy but will require a partial medial pedicle resection. This often is possible only after facet resection.

Methods

Literature search

The following searches of the literature from 2000 to September 2020 were made:

1. A core search by computer-aided searching of PubMed (www.ncbi.nlm.nih.gov/pubmed), Google Scholar and the Cochrane Library databases in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. “Thoracic” and “endoscopic” were identified as key search terms from an initial recent literature screen and were secondarily used in combination with “disc”, “discectomy”, “myelopathy” and “transforaminal” (filter Human) in turn for a full literature analysis.

2. A standard search including:
   a) personal bibliographies held by the authors.
   b) citation tracking from all papers identified by the above strategies.

Titles and abstracts meeting the inclusion criteria were screened and all full-text articles published in peer-reviewed journals independently reviewed by two of the authors (RDSG and JNAG). Papers were sought in all languages with translation to English performed if required and reference lists of each study checked for missing reports. Animal studies, biomechanical studies, purely technical notes with no quantitative outcome data and meeting presentation abstracts were excluded. Case reports were referenced and included in the data analysis.

Quality assessment

The methodological quality of all patient series found (non-comparative studies with more than three patients) was assessed using the first eight items of the Methodological Index for Non-Randomized Studies checklist.27 Each study was scored on eight items from 0 to 2 by two of the authors and any disagreements were referred to the third author (maximum value 16 – see Table 1: 0 = not reported, 1 = inadequate, 2 = adequate).

Data extraction

Data from each study were extracted to populate Tables 2 and 3. Patient characteristics, pathology of the thoracic disease, level(s) of surgery and factors influencing post-operative course were sought. Particular care was taken to tabulate all patient-reported outcome measures (PROMs) to allow conclusions to be drawn as to the efficacy of full endoscopic surgery.

Results

Using the primary search terms in combination with each of the secondary terms on PubMed yielded 112 results, 68 of which were unique when collated. Searching Google scholar for article titles containing the same terms in combination, published over the same period (2000–2020) yielded 56 results, 31 of which were unique. When combined, the literature searches of these two databases revealed a total of 81 full articles for review (Fig. 7). An additional 14 papers were added from personal database and bibliographies. Fifty-one were immediately excluded following abstract review. Thirteen articles were discounted on full-text review as they were primarily descriptions of open approaches or techniques using tubular devices to facilitate exposure. The year of publication of those included ranged from 2006 to 2020 with the majority having been published in the last two years. Seventeen of the studies were non-comparative...
### Table 2. Published patient series of Full Endoscopic treatments of thoracic disorders

| Patient series | Pathology         | Technique | N (m:f) | Age (range) | Follow-up months (range) | Anaesthesia | Op time mins (range) | Stay (days) | Excellent / Good / Fair (%) | VAS Back (Dec. %) | VAS Leg (Dec. %) | ODI (Improv. %) | JOA score (RR %) | MINORS score | Complications | Comments |
|----------------|-------------------|-----------|---------|-------------|--------------------------|-------------|----------------------|-------------|-----------------------------|-----------------|-----------------|-----------------|-----------------|--------------|---------------|----------|
| An, 2019<sup>56</sup> | OLF T2:T12       | IL        | 18 (8:10) | 59 (44–77) | 17 (12–24)               | LA          | 172 ± 30             | 5 ± 2        | 77                         | 86              | 68              | 67              | 48              | 13           | Dural tear x 2 | Nil      |
| Bae, 2019<sup>57</sup> | Disc T2:T6       | TF        | 14 (12:2) | 42 (26–69) | 43 (6–120)                | LA          | 90 ± 2               | 90          | 79                         | 81              | 11              | 11              | 11              | 11           | Motor weakness x 1 | 11       |
| Bae, 2020<sup>58</sup> | Disc T2:L1       | TF        | 92 (57:35) | 49          | 38                       | LA          | 90 ± 2               | 90          | 79                         | 81              | 11              | 11              | 11              | 11           | Motor weakness x 1 | 11       |
| Cheng, 2020<sup>59</sup> | OLF (5), Disc (5), OPLL (2) | IL        | 12 (6:6)  | 55 (27–73) | 12                       | LA          | 85 (70–120)          | 4 (3–6)     | 92                         | 54              | 57              | 58              | 74              | 10           | Dural tear x 1; Transient paralaxy x 1 | 7       |
| Choi, 2019<sup>60</sup> | Disc T2:T12      | TF        | 14 (6:8)  | 48 (21–75) | 60 (15–89)               | LA          | 61 ± 2               | 12          | 54                         | 76              | 97              | 29              | 33              | 9            | Secondary surgery x 2 | Nil     |
| Guo, 2019<sup>61</sup> | T3:12            | TF        | 6 (4:2)   | 13 (11–14) | LA                       | 48 (40–60)  | 100 ± 2              | 100         | 76                         | 97              | 29              | 29              | 77              | 7            | Motor weakness x 1 | 7       |
| Lee H, 2006<sup>62</sup> | Disc T2:T12      | TF        | 8 (3:5)   | 51 (31–75) | 27 (12–48)               | LA          | 55 ± 2               | 55          | 2.5 (1–6)                  | 51              | 51              | 51              | 51              | 11           | Dural tear x 2; | 11       |
| Lee S, 2018<sup>63</sup> | Disc T3:12       | TF        | 87 (51:36) | 10 (1–56)  | LA                       | 71          | 51 ± 2               | 71          | 51                         | 71              | 46              | 46              | 54              | 11           | Dural tear x 2 | 11       |
| Li X, 2020<sup>64</sup> | OLF (5), Disc (5), OPLL (2) | IL        | 30 (17:13) | 61 (44–84) | 21                       | LA          | 167 (100–240)        | 46          | 46                         | 77              | 59              | 59              | 72              | 10           | Dural tear x 2 | 10       |
| Li Z, 2020<sup>65</sup> | Disc (12), stenosis (4), T3:T12 | TF        | 16 (12:4) | 54          | 12                       | LA          | 48 (45–60)           | 77          | 93                         | 59              | 59              | 59              | 72              | 10           | Interostral neuralgia x 2 | 10       |
| Nie, 2018<sup>66</sup> | Disc T5:12, Disc (4), stenosis (3), OLL (4), facet cyst (1) T1:12 | TF        | 55 (58:32) | 52 (23–82) | 18                       | GA          | 50 ± 2               | 77          | 54                         | 77              | 55              | 55              | 31              | 13           | Epidural haematoma x 2 | 13       |
| Ruetten, 2018<sup>67</sup> | Disc T6:T12, Disc (3), T3:T12 | TF        | 26 (10:16) | 58 (23–82) | 6                        | GA          | 90 (40–155)          | 3.0 (2–6)   | 55                         | 73              | 73              | 73              | 73              | 11           | Dural tear x 2 | 11       |
| Shen, 2018<sup>68</sup> | Disc T5:T12      | TF        | 16 (10:6) | 55 (28–78) | 21 (7–60)                | LA          | 90 (55–180)          | 90          | 73                         | 81              | 81              | 81              | 57              | 9            | Dural tear x 2 | 9        |
| Xiaobing, 2018<sup>69</sup> | OLF/Spinal OPLL T1:12 | TF        | 14 (7:7)  | 57 (33–78) | 21                       | LA          | 90 ± 2               | 90          | 73                         | 81              | 81              | 81              | 57              | 9            | Dural tear x 2 | 9        |
| Yang, 2019<sup>70</sup> | Thoracic TB | TF/TP      | 75        | 56 ± 12    | 36                       | GA          | 182 (130–250)        | 96 (Fusion) | 85                         | 85              | 85              | 85              | 10              | 10           | Root irritation x 6; Graft absorption x 3 | 10       |
| Yu, 2020<sup>71</sup> | OPLL (T7:L1)     | TF        | 15 (7:8)  | 56 (41–71) | 20 (13–32)               | LA          | 79 (43–132)          | 79          | 4.1 ± 1.1                  | 71              | 64              | 79              | 40              | 10           | Root irritation | 10       |
| Cohort study | Disc | TF        | 8 (6:2)   | 42 (26–57) | 3                        | LA          | 78 ± 11              | 78          | 78                         | 78              | 78              | 78              | 78              | 78           | Muscle weakness x 1 | 78       |

Note. TF, transforaminal; IL, interlaminar; TP, transpedicular; TR, transthoracic retropleural; LA, local anaesthetic plus sedation; GA, general anaesthesia; ODI, Oswestry Disability Index: improvement %; VAS, Visual Analogue Score: decrease %; OPLL, Ossification of Posterior Longitudinal Ligament; TB, Tuberculosis; OLF, Ossification of Ligamentum Flavum; JOA, Japanese Orthopaedic Association; RR, recovery rate = (postoperative JOA - preoperative JOA) / 11 or 18 or 29 - preoperative JOA x 100 %; MINORS, Methodological Index for Non-Randomized Studies: scored out of 16.
patient series with numbers included totalling 511, ranging from 6 to 92 (Table 2). One report randomized eight patients to transforaminal endoscopy and eight to open posterior laminectomy using a random number table method. No information was provided regarding allocation concealment and data were incomplete. The trial is therefore referenced here as a cohort study rather than a randomized controlled trial. Thirteen articles were case reports with technical descriptions and limited outcome data (Table 3).

### Technical aspects

Twenty articles used full endoscopy via a transforaminal approach and six via an interlaminar approach. The remainder were mixed, extrarforaminal, transpedicular or transcorporeal. The technical aspects of surgery were similar in all papers with use of comparable instrumentation systems. Three surgical teams used a laser to aid decompression and one an ultrasonic bone knife. Kolcun et al. described using robotic technology to aid instrumentation placement at the correct thoracic level. Operative time ranging from 48 to 250 minutes was heavily dependent on the number of levels involved and the pathology present.

### Functional outcomes

All the patient series reported one or more functional outcome measures (Table 2). Of these, eight reported scores on one of the Japanese Orthopaedic Association (JOA) scoring systems allowing calculation of a recovery rate. This led to four surgical results falling into Excellent/Good category (scores > 50%) and four into a Fair category (25–49%). All four case reports (less robust evidence) with JOA recovery rates suggested Excellent/Good results. Where reported there was a reasonable improvement in Visual Analogue Score (VAS) for back (78 ± 14%) and leg (75 ± 19%) pain post surgery. Mean Oswestry Disability Index (ODI) improved from 60 ± 7% to 19 ± 11% at final outcome (p < 0.001, paired t-test).

### Complications

Complications are listed in Tables 2 and 3. Dural tears were reported in 11 of the 460 patients (2%), transient paraesthesia or neuralgia in 10 (2%), revision surgery in seven (1.5%), neurological injury in three (0.6%) and epidural haematoma in three (0.6%).

### Review limitations

Although a search protocol was established framed in terms of patients undergoing surgery for thoracic pathology (P), receiving full endoscopic surgical intervention (I), with comparisons to open surgery where available (C), and detailing patient-reported outcome measures and complications (O), individual search strategies were not formed for each identified source to take account of differences in indexing. The search was also primarily, although not exclusively, of original studies and any ‘meta’ literature, rather than extending this to secondary sources including unpublished/grey literature.
The current literature remains limited to Level IV evidence. Only one study had results with comparison to an open procedure and provided no comparison with continuation of conservative therapies. Where specified, similar endoscopic instrumentation systems were used (Clarus US, joimax GmbH, RWOspine GmbH, Spinendos GmbH) and it was assumed that any differences in system were not a factor materially influencing the reported outcomes.

**Discussion**

It is clear from the results of this review that the future lies with the perfection of endoscopic surgical techniques applicable to the treatment of thoracic pathology. In the last five years there has been a significant increase in the literature pertaining to endoscopic procedures. Although primarily evidence is derived from patient series with Level IV evidence, there is a reasonable uniformity in reported outcomes with assessments falling into the Excellent or Good category.

Considering thoracic discectomy, 14 reports were available with success rates equalling those reported elsewhere for grouped posterolateral approaches. Perhaps of greater significance is the clear evidence for a lower complication rate and shorter hospital stay. Complications common with open surgery, including vertebral column instability, cerebrospinal fluid leak/pleural fistula, thoracic viscera injury, and intercostal neuralgia were not reported in any of the papers. Interestingly, neither was wrong-level surgery, presumably due to the necessity for multiple image intensifier radiographs during the procedure. In the future, it is likely that radiation dosage during endoscopy will be reduced by new innovations in image guidance, whether using localizing cameras, ultrasonic, electromagnetic or robotic technology, designed specifically for spinal application.

Based on the natural history of disc prolapse with a gradual resolution of symptoms with time by fragment resorption, it is generally recognized that resection of only the protruding fragment of a disc prolapse is required if surgery is essential. This approach lends itself to minimally invasive techniques and obviates the necessity for spinal fusion after complete discectomy. This probably even applies to some of the situations where fusion has
been felt essential in the past, such as cases of multilevel herniation, herniation in association with Scheuermann’s disease and herniation at the thoracolumbar junction. The largest series in this review,10 provides supportive evidence for this at the thoracic levels with a < 2% reported recurrence of prolapse at two years. The transforaminal approach has a distinct advantage over an interlaminar approach in that instruments do not need to be inserted through the thecal sac and the herniation, as the protruding disc is pulled out posterolateral to the cord. In an interlaminar approach the cannula and any curettes inserted occlude direct vision of the thecal sac unless rotated, resulting in a higher potential for cerebrospinal fluid (CSF) leakage from dural injury. Interlaminar surgery was mainly limited to patients with stenosis and ossification of the ligamentum flavum and/or posterior longitudinal ligament. In contrast to results from open techniques, that almost always require associated anterior or posterior spinal fusion,62 they found no postoperative neurologic deterioration. It has been stated that endoscopy is inappropriate for the treatment of giant thoracic disc herniation, described as occupying greater than 40% of the thoracic canal diameter,63 as an intradural extension has been reported in 15–70%.1 Although use of a mini-thoracotomy or a retropleural approach have both been recommended,64 modern advancements in imaging, coupled with laser resection, may now allow surgeons to consider full endoscopy for even these difficult pathologies.

During any spinal surgery preservation of the blood supply to the cord is paramount. To mitigate against damage, Court et al1 suggested that at least in transthoracic approaches, arteriography to locate the Artery of Adamkiewicz should be considered as this could determine the optimal side for surgical exposure. Arterial damage is less likely with full endoscopy, since the approaches will be posterior or posterolateral, hence arteriography is not generally performed, avoiding its associated complications. There was no suggestion from our literature review that vascular impairment was a cause of ongoing myelopathy.

Uses of endoscopy for advanced spinal disease from infection and tumour have been reported in several publications.65,66 One study (not included in Table 2 as treatments were primarily to the lumbar spine) described use of endoscopy to treat infective spondylodiscitis. After cannula insertion and abscess drainage the authors used endoscopy to enhance vision with minimal invasion for debridement and sequestrectomy.65 Yang et al, in a relatively large series of patients with tuberculosis, describe coupling of percutaneous decompression of the spine with allografting and percutaneous pedicle screw fixation.41 They reported excellent outcomes with 96% achieving acceptable fusion, although it was noted that their results were only from patients with single-level disease and small abscesses. The advantages of a water-mediated procedure with flushing of the targeted area were emphasized. Telfeian et al35 describe the potential for use of endoscopy in tumour resection.

Complications from open surgery have been considered by several authors.13,67 Lubelski et al13 found that the mean complication rate for thoracotomy was 39% (n = 453), for the lateral extracavitary approach 17% (n = 157) and for costotransversectomy 15% (n = 164), but noted that 25% of patients receiving a thoracotomy were undergoing a palliative decompression and stabilization for spinal metastases. Brotis et al67 reviewed different approaches for treatment of only thoracic disc herniation. Their meta-analysis included 15 primarily retrospective cohort studies of 1036 patients. Medical and surgical-site complications were the most common source of morbidity at 21% and 11%, respectively. CSF related and neurological complications were estimated to be 8% and 5%. In contrast, results from this review for endoscopy, although on smaller reported numbers, show significantly lower total complications at 8%. Heat injury from use of laser or radiofrequency might be a concern for the surgeon due to the anatomy of the thoracic canal, with a higher density of the spinal cord compared to the multiple roots in the lumbar region.68 Although there is less CSF to buffer against heat, full endoscopy is performed under continuous irrigation mitigating this risk. It is interesting to note that, with respect to the open approaches, the lateral and posterolateral approaches had lower overall complications than the anterior approaches (although the latter were reduced with thoracoscopy), but were more liable to inadequate decompression. Whether there are any long-term consequences of smaller yet better-visualized areas of decompression with full endoscopic techniques will only show up in studies with longer follow-up. The likelihood is that the impact of further advancements in imaging with 4HD, 3-D and robotic technology69 will improve surgical outcomes and reduce complications further.

Making an accurate interpretation of the current status of endoscopic surgery is to an extent limited by the small size of almost all the studies. However, the comparative open surgical cohorts are not actually much larger, a reflection of the relative rarity of most thoracic pathologies and hence a limitation of the number of cases presenting to a single unit. Probably for this reason randomized
controlled trials producing Level I evidence are not available. The centralization of spinal surgery to regional centres in the UK and elsewhere should allow the production of better-quality evidence in the future.

Conclusion

Current literature demonstrates an international adoption of full endoscopic techniques for the treatment of thoracic spine pathology. The majority of reports describe a transfornamental approach for disc prolapse with interlaminar access used for the treatment of significant canal stenosis. Overall, there is now a moderate expectation of Excellent/Good postoperative outcomes with fewer complications than after open surgery. The increasing number of publications in the last three years suggests that full endoscopy is the technique of choice in many centres and will become the universal standard of patient care.

AUTHOR INFORMATION

1. Aberdeen Royal Infirmary, Aberdeen, UK.
2. Ligamenta Spine Centre, Frankfurt am Main, Germany.
3. The Royal College of Surgeons of Edinburgh, Edinburgh, UK.

Correspondence should be sent to: Rory D. S. Gibson, Aberdeen Royal Infirmary, Foresterhill, Aberdeen, AB25 2ZU, UK.

Email: rds.gibson@gmail.com

OPEN ACCESS

© 2021 The author(s)

This article is distributed under the terms of the Creative Commons Attribution-Non Commercial 4.0 International (CC BY-NC 4.0) licence (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed.

ICMJE CONFLICT OF INTEREST STATEMENT

RDSG declares no conflict of interest relevant to this work.

RW reports consultancy for joimax GmbH and a webinar series for joimax GmbH outside the submitted work.

JNAG reports consultancy for joimax GmbH, a patent for an endoscopic retractor for joimax GmbH and a webinar series for joimax GmbH, all outside the submitted work.

FUNDING STATEMENT

The author or one or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article.

REFERENCES

1. Court C, Mansour E, Bouthors C. Thoracic disc herniation: surgical treatment. Orthop Traumatol Surg Res 2018;104:531–540.
2. Hurley ET, Maye AB, Timlin M, Lyons FG. Anterior versus posterior thoracic discectomy: a systematic review. Spine (Phila Pa 1976) 2017;42:E437–E445.
3. Currier BL, Eismont FJ, Green BA. Transthoracic disc excision and fusion for herniated thoracic discs. Spine (Phila Pa 1976) 1994;19:323–328.
4. Horowitz MB, Moossey JJ, Julian T, Ferson PF, Hunekc K. Thoracic disectomy using video assisted thoracoscopy. Spine (Phila Pa 1976) 1994;19:1082–1086.
5. Anand N, Regan J]. Video-assisted thoracoscopic surgery for thoracic disc disease: classification and outcome study of two consecutive cases with a 2-year minimum follow-up period. Spine (Phila Pa 1976) 2002;27:871–879.
6. Mayer HM. The microsurgical anterior approach to T5-T10 (Mini-TTA). In: Mayer HM, ed. Minimally invasive spine surgery: a surgical manual. Berlin: Springer, 2000:59–66.
7. Robinson WA, Nassr AN, Sebastian AS. Thoracic disc herniation, avoidance, and management of the surgical complications. Int Orthop 2019;43:817–823.
8. Fessler RG, Sturgill M. Review: complications of surgery for thoracic disc herniation. Surg Neurol 1998;49:609–618.
9. Moon SJ, Lee JK, Jang JW, Hur H, Lee JH, Kim SH. The transdural approach for thoracic disc herniations: a technical note. Eur Spine J 2010;19:1206–1211.
10. Mirkovic S, Garfin SR. Costotransversectomy: a posterolateral approach to the thoracic spine. Orthopedics 1993;3:221–224.
11. Le Roux PD, Haglund MM, Harris AB. Thoracic disc disease: experience with the transpedicular approach in twenty consecutive patients. Neurosurgery 1993;33:58–66.
12. Schmidt MH, Larson SJ, Maimon DJ. The lateral extracavitary approach to the thoracic and lumbar spine. Neurosurg Clin N Am 2004;15:427–441.
13. Lubelski D, Abdullah KG, Steinmetz MP, et al. Lateral extracavitary, costotransversectomy, and transthoracic thoracotomy approaches to the thoracic spine: review of techniques and complications. J Spinal Disord Tech 2013;26:222–232.
14. Min JH, Jang JS, Lee SH. Clinical results of ossification of the posterior longitudinal ligament (OPLL) of the thoracic spine treated by anterior decompression. J Spinal Disord Tech 2008;21:116–119.
15. Takahata M, Ito M, Abumi K, Kotani Y, Sudo H, Minami A. Clinical results and complications of circumferential spinal cord decompression through a single posterior approach for thoracic myelopathy caused by ossification of posterior longitudinal ligament. Spine (Phila Pa 1976) 2008;33:1199–1208.
16. Hanai K, Ogikubo O, Miyashita T. Anterior decompression for myelopathy resulting from thoracic ossification of the posterior longitudinal ligament. Spine (Phila Pa 1976) 2002;27:1070–1076.
17. Regev G], Salame K, Behrbak E, Keynan O, Lidar Z. Minimally invasive transfornamental, thoracic microscopic discectomy: technical report and preliminary results and complications. Spine J 2012;12:570–576.
18. Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine: a preliminary report. Clin Orthop Relat Res 1983;174:127–132.
19. Gibson JNA, Cowie JG, Ipenburg M. Transforaminal endoscopic spinal surgery: the future ‘gold standard’ for discectomy? The Surgeon 2012;10:290–296.
20. Choi KY, Eun SS, Lee SH, Lee HY. Percutaneous endoscopic thoracic discectomy: transfornamental approach. Minim Invasive Neurosurg 2010;53:25–28.
21. Chiu JC, Javidan N, Thacker J. Posterolateral endoscopic thoracic microdecompressive discectomy. J Minim Invasive Spine Surg Tech 2008;3:3.
22. Wagner R, Telfeian AE, Ipenburg M, et al. Transforaminal endoscopic foraminoplasty and discectomy for the treatment of a thoracic disc herniation. World Neurosurg 2016;90:194–198.
23. Hofstetter CP, Ahn Y, Choi G, et al. AO Spine consensus paper on nomenclature for working channel endoscopic spinal procedures. Global Spine J 2020;10:117–121S.
Surgical results and prognostic factors following percutaneous full endoscopic posterior decompression for thoracic myelopathy caused by ossification of the ligamentum flavum. Sci Rep 2020;10:1395.

Mober D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.

Bidwell S, Jensen MF. Extent on health technology assessment (HTA) information resources. Chapter 3: Using a search protocol to identify sources of information: the COSI Model. National Information Center on Health Services Research and Health Care Technology/NICHSR. 2003. https://www.nlm.nih.gov/archive/20060905/nichsr/eh/ehal/halhtml (last accessed 20 November 2020).

Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological Index for Non-Randomized Studies (MINORS): development and validation of a new instrument. ANZ J Surg 2003;73:712–716.

An B, Li X-C, Zhou C-F, et al. Percutaneous full endoscopic posterior decompression of thoracic myelopathy caused by ossification of the ligamentum flavum. Eur Spine J 2019;28:492–501.

Bae J, Chanchan S, Shin S-H, Lee S-H. Percutaneous endoscopic thoracic discectomy in the upper and midthoracic spine: a technical note. Neurosurgery 2019;86:148–153.

Bae J, Chanchan S, Shin S-H, Lee S-H. Transforaminal endoscopic thoracic discectomy with foraminoplasty for the treatment of thoracic disc herniation. J Spine Surg 2020;6:397–404.

Cheng XX, Chen B. Percutaneous endoscopic thoracic decompression for thoracic spinal stenosis under local anesthesia. World Neurosurg 2020;139:488–494.

Guo C, Zhu D, Kong Q, et al. Transforaminal percutaneous endoscopic decompression for lower thoracic spinal stenosis. World Neurosurg 2019;128:e504–e512.

Lee HY, Lee S-H, Kim D-Y, Kong BJ, Ahn Y, Shin S-W. Percutaneous endoscopic thoracic discectomy: posterolateral transforaminal approach. J Korean Neurosurg Soc 2006;40:58–62.

Lee SH. Posterolateral endoscopic thoracic discectomy: transforaminal approach. Neurologia Spinalis Medico Chirurgica 2018;1:20.

Li Z, Zhao HL, Cao Z, Shang WL, Hou SX. Technical notes and clinical efficacy analysis of full-endoscopic thoracic discectomy via transforaminal approach. Zhonghua Yi Xue Za Zhi 2020;100:279–285.

Nie HF, Liu XX. Endoscopic transforaminal thoracic foraminotomy and discectomy for the treatment of thoracic disc herniation. Minim Invasive Surg 2013;2013:264105.

Ruetten S, Hahn P, Oezdemir S, et al. Full-endoscopic uniportal decompression in disc herniations and stenosis of the thoracic spine using the interlaminar, extraforaminal, or transforaminal retroperitoneal approach. J Neurosurgery Spine 2018;29:157–168.

Ruetten S, Hahn P, Oezdemir S, Baraliakos X, Godolias G, Komp M. Operations of soft or calcified thoracic disc herniations in the full-endoscopic uniportal extraforaminal technique. Pain Physician 2018;21:E331–E340.

Shen J. Full endoscopic transforaminal discectomy under local anesthesia for thoracic disc herniations: a case series. J Spine 2018;7:013.

Xiaobing Z, Xingchen L, Honggang Z, et al. “U” route transforaminal percutaneous endoscopic thoracic discectomy as a new treatment for thoracic spinal stenosis. Int Orthop 2019;43:825–832.

Yang J-S, Chu L, Deng R, et al. Treatment of single level thoracic tuberculosis by percutaneous endoscopic debridement and allograft via the transforaminal approach combined with percutaneous pedicle screw fixation: a multicenter study with a median follow-up of 36 months. World Neurosurg 2019;122:614–621.

Yu Q, Yang J, Chu L, Shi L, Deng Z, Ke Z. Clinical effectiveness of percutaneous endoscopic spinal surgery via transforaminal approach for single-level thoracic ossification of the posterior longitudinal ligament. 2020. Available at https://www.researchsquare.com/article/rs-30878/v1 (date last accessed 23 November 2020).

Zeng T, Guo D. Transforaminal endoscope for the treatment of thoracic disc herniation. J Clin Nursing Res 2020;4:9–11.

Hurr J-W, Kim J-S, Seung J-H. Full-endoscopic interlaminal discectomy for the treatment of a dorsal migrated thoracic disc herniation: case report. Medicine (Baltimore) 2019;98:e15541.

Jia QZ, He XJ, Zhao LT, Li S-Q. Transforaminal endoscopic decompression for thoracic spinal stenosis under local anesthesia. Eur Spine J 2018;27:465–471.

Lee Y-C, Ok W-K, Baik S-H, Kim H-J, Kwon O-S, Kim K-H. Removal of a vertebral metastatic tumor compressing the spinal nerve roots via a single-port, transforaminal, endoscopic approach under monitored anesthesia care. Pain Physician 2012;15:297–302.

Kolcum JPG, Wang MY. Endoscopic treatment of thoracic discitis with robotic access: a case report merging two cutting-edge technologies. World Neurosurg 2019;126:418–422.

Kong W, Ao J, Cao G, Xia T, Liu L, Liao W. Local spinal cord decompression through a full endoscopic percutaneous transpercutaneous approach for cervicothoracic ossification of the posterior longitudinal ligament at the T1-T2 level. World Neurosurg 2018;112:287–293.

Liu L, Li Q, Ao J, Du Q, Xin Z-J, Liao W-B. Posterior percutaneous endoscopic technique through bilateral translaminar osseous channels for thoracic spinal stenosis caused by ossification of the ligamentum flavum combined with disk herniation at the T10-11 level: a technical note. World Neurosurg 2020;133:335–341.

Liu W, Yao L, Li X, et al. Percutaneous endoscopic thoracic discectomy via posterolateral approach: a case report of migrated thoracic disc herniation. Medicine (Baltimore) 2019;98:e17579.

Liu Y, Xu B-S, Ning J, Jiang H-F, Yang Q. Preliminary experience of percutaneous transforaminal endoscopic spine system in thoracic discectomy for disc herniation. Tianjin Yi Yao 2017;45:121–124.

Miao X, He D, Wu T, Cheng X. Percutaneous endoscopic spine minimally invasive technique for decompression therapy of thoracic myelopathy caused by ossification of the ligamentum flavum. World Neurosurg 2018;114:8–12.

Middleton SD, Wagner R, Gibson JNA. Multi-level spine endoscopy: a review of available evidence and case report. EFORT Open Rev 2017;2:317–323.

Quillo-Olvera JA, Kim J-S. A novel, minimally invasive hybrid technique to approach intracranial herniated thoracic discs. Oper Neurosurg (Hagerstown) 2020;19:E60–E66.

Telfeian AE, Choi DB, Aghion DM. Transforaminal endoscopic surgery under local analgesia for ventral epidural thoracic spinal tumor: case report. Clin Neurol Neurosurg 2015;134:7–3.

Wu B, Huang X, Wang P, et al. Thoracic disc herniation at T7-8 in a 41-year-old woman with a 16-year course was treated with percutaneous endoscopic thoracic discectomy: a case report. JOCRiMS 2017;2:21–26.

Richardson WS, Wilson MC, Nishikawa J, Hayward RS. The well-built clinical question: a key to evidence-based decisions. ACP J Club 1995;123:A12–A13.

Schild C, Adams MB, Owens T, Keitz S, Fontelo P. Utilization of the PICO eText on health technology assessment (HTA) information systems for systematic reviews and meta-analyses: the PRISMA statement. J Clin Nurse 2018;21:E331–E340.
59. OCEBM Levels of Evidence Working Group. The Oxford 2011 levels of evidence. Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 (last accessed 20 November 2020).

60. Baek G-S, Kim Y-S, Lee M-C, Song J-W, Kim S-K, Kim I-H. Fragmentectomy versus conventional microdiscectomy in single-level lumbar disc herniations: comparison of clinical results and recurrence rates. J Korean Neurosurg Soc 2012;52:210–214.

61. Osman NS, Cheung ZB, Hussain AK, et al. Outcomes and complications following laminectomy alone for thoracic myelopathy due to ossified ligamentum flavum. Spine (Phila Pa 1976) 2018;43:E842–E848.

62. Chen Z-Q, Sun C-G; Spine Surgery Group of Chinese Orthopedic Association. Clinical guideline for treatment of symptomatic thoracic spinal stenosis. Orthop Surg 2015;7:208–212.

63. Hott JS, Feiz-Erfan I, Kenny K, Dickman CA. Surgical management of giant herniated thoracic discs: analysis of 20 cases. J Neurosurg Spine 2005;3:191–197.

64. Sharma SB, Kim J-S. A review of minimally invasive surgical techniques for the management of thoracic disc herniations. Neurospine 2019;16:24–33.

65. Lin C-Y, Chang C-C, Chen Y-J, et al. New strategy for minimally invasive endoscopic surgery to treat infectious spondylodiscitis in the thoracolumbar spine. Pain Physician 2019;22:281–293.

66. Telfeian AE, Oyelese A, Fridley J, Doberstein C, Gokaslan ZL. Endoscopic surgical treatment for symptomatic spinal metastases in long-term cancer survivors. J Spine Surg 2020;6:372–382.

67. Brotis AG, Tasiou A, Paterakis K, Tzerefos C, Fountas KN. Complications associated with surgery for thoracic disc herniation: a systematic review and network meta-analysis. World Neurosurg 2019;132:334–342.

68. Choi G, Munoz-Suarez D. Transforaminal endoscopic thoracic discectomy: technical review to prevent complications. Neurospine 2020;17:S58–S65.

69. Fiani B, Quadri SA, Farooqui M, et al. Impact of robot-assisted spine surgery on health care quality and neurosurgical economics: a systemic review. Neurosurg Rev 2020;43:17–25.