

Full endoscopic treatment of dural tears in lumbar spine surgery

Joachim M. Oertel^{1,2} · Benedikt W. Burkhardt¹

Received: 9 November 2016/Revised: 26 March 2017/Accepted: 17 April 2017/Published online: 20 May 2017
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Abstract

Purpose An incidental durotomy is a common complication of spinal surgery. Its treatment remains challenging, especially in endoscopic procedures. The objective of this study is to describe a technique for endoscopic dural closure which is safe and effective.

Methods From a prospective database all endoscopic spinal procedures with incidental durotomy were identified. Retrospectively, video recordings were analysed with a special reference to the applied technique of dural closure. Additionally 1, 6 and 12 week follow-up examinations were evaluated for clinical outcome and associated complications.

Results Out of 212 consecutive patients, an intraoperative dural tear was observed in nine patients (4.2%). A dural tear occurred in 1.1% of cases of lumbar disc herniation, in 7.9% of cases with lumbar spinal stenosis, in 37.5% of cases with a synovial cyst. An autologous muscle sample was harvested within the operative field and grafted at the dural defect in several layers. Fixation of the transplantation and watertight closure were achieved by the application of fibrin sealant with gelfoam. The mean time for dural

closure was 209 s (range 47–420 s). Postoperatively no CSF fistula, no new deficits nor worsening of a pre-existing neurological deficit occurred. None of the patients had problems with wound healing, or discomfort which could be related to the CSF leak.

Conclusions Dural closure with an autologous muscle graft in combination with fibrin sealant patch is a fast, safe and alternative technique for the management of dural tear in microendoscopic surgery.

Keywords Dural tear · Dural closure · Endoscopy · Cerebrospinal fluid leak · Spinal surgery

Introduction

Endoscopic spinal surgery is an accepted technique for the treatment of degenerative spinal disorders [1].

An incidental dural tear is a common complication in spinal surgery. It's incidence is affected by several factors such as patient's age, diagnosis, surgeon's experience, presence of synovial cyst and type of surgical procedure. It may range from less than 1 up to 17%. A non-treated dural tear is a complication which might cause a variety of symptoms such as postural headache, nausea, vomiting and/or pseudomeningocele formation. More serious complications such as meningitis, intracranial haemorrhage, nerve root herniation with consecutive radicular symptoms, persistent leakage of cerebrospinal fluid (CSF) with delayed wound healing and wound infection have also been described [2].

Several reports on perioperative management and different surgical techniques for the treatment of dural tears have been published [3, 4]. In contrast there are very few reports on the management of dural tears in the field of

Electronic supplementary material The online version of this article (doi:10.1007/s00586-017-5105-8) contains supplementary material, which is available to authorized users.

✉ Joachim M. Oertel
oertelj@freenet.de

¹ Department of Neurosurgery, Saarland University Medical Center, Saarland University Faculty of Medicine, Homburg, Saarland, Germany

² Klinik fuer Neurochirurgie, Universitaetsklinikum des Saarlandes, Kirrbergerstraße 100, Gebaeude 90.5, 66424 Homburg, Germany

minimally invasive—and especially endoscopic—spine surgery [5–7]. The incidence of a dural tear in endoscopic techniques is low [8–10]. In case of a dural tear, the standard technique of suturing the tear is almost always impossible under endoscopic view because access to the dural tear and handling of the surgical instruments are limited. However, suturing the dura through a tubular retractor is possible if special instruments are available and if the surgeon is used to them [6, 11, 12]. If dural repair by suture is not possible, the surgeon might be forced to terminate the endoscopic or tubular-assisted procedure and change to open surgery [7]. Recently, it has been reported that 79.4% spine surgeons perform dural repair without direct suturing using fibrin sealant patch or another products in conventional spine surgery [13]. Even though placing a patch on the dural surface has been used for decades it has never been assessed if this technique ensures clinical success when applied via endoscopic tube systems followed by early postoperative patient mobilization.

To the best of our knowledge, this is the first detailed report about endoscopic dural tears and a technique for endoscopic dural closure with an autologous muscle graft and fibrin sealant patch that demonstrated the effectiveness of this technique.

Materials and methods

All patients who underwent endoscopic spinal surgery from January 2011 to August 2016 were identified from a prospectively collected database. All procedures were performed with the EasyGO[®] System (Karl Storz Company, Tuttlingen, Germany). Under endoscopic visualization, cervical, thoracic and lumbar spine procedures have been performed in standard bimanual microsurgical technique. Patient demographics, preoperative and postoperative patient records, and surgical records including the intraoperative video documentation were reviewed. Special focus was given to intraoperative complications and postoperative course. The surgical technique of posterior cervical foraminotomy and lumbar spine surgery has been described in detail elsewhere [14, 15].

Results

Patient collective

Over a 5 year and 8 month period, 212 consecutive patients underwent endoscopic cervical, thoracic and lumbar spine surgery. In nine patients (four men and five women) with a mean age of 57 years (range 39–74) a dural tear occurred (4.2%).

In all cases with incidental dural tear a unilateral approach to the lumbar spine was performed. None of the patients had a history of previous spinal surgery.

Two patients were operated via a 15 mm and seven patients via a 19 mm tubular retractor. The mean surgical time was 77 min (range 50–115 min) and the mean time per segment was 60 min (range 29–85 min). The mean time for dural closure was 209 s (range 47–420 s). A compilation of patient demographics, of the performed procedure, of the localization of the dural tear, of the underlying pathology and of the time for dural closure is shown on Table 1.

Dural tears in detail

In lumbar spinal canal stenosis the incidence of dural tear was 7.9% (5 cases). In two cases additionally to the posterior spinal canal stenosis a disc prolapse was present.

In one case of stenosis with a disc herniation, the tear occurred mediadorsal while using a diamond drill to thin out the base of the spinous process for contralateral decompression. The dural tear was located medial under the base of the spinous process. The contralateral decompression was continued around the dural tear with a Kerrison punch (see Fig. 1). After decompression, dural closure was done as described below.

In the other cases of stenosis with disc herniation, the dural tear occurred using a Kerrison punch for decompression of the shoulder of the nerve root. A subligamentous disc herniation misplaced the dural sac and the nerve root laterally. The decompression was performed for release of the nerve root from the lamina. The dural sac and the nerve root were adherent to the lamina. Once a dural tear occurred, the author used a suction or a dissector to cover and retract the dural tear and decompression was carried out furthermore.

Three dural tears occurred while decompressing the lateral aspect of the dural sac to expose the floor of the spinal canal and the lumbar disc prolapses. After successful decompression a nerve hook was used to release adhesive tissue between disc space and dura. One dural tear was located at the ventral aspects of the dural sac, and the other dura tear was located at the lateral aspect of the dural sac.

In synovial cyst surgery the incidence of dural tear was 37.5% (three cases). This entity is well known for the massive adherence of the cyst tissue to the thecal sac and the high frequency of CSF leakage. Two patients underwent surgery for a left-sided L4–5 synovial cyst and one patient for a right-sided L5–S1 synovial cyst. In two cases, the dural tear occurred at the initial step of the procedure. After exposure of the dura and the cranial part of the synovial cyst, a nerve hook with a blunt tip was used to

Table 1 Patient demographic, clinical and intraoperative data

Patient number	Gender	Age at surgery (years)	Diagnosis	Procedure	Outer diameter of working trocar (mm)	Localization of dural tear	Nerve fascicle herniation	Time for dural closure (s)
1	Female	74	L4–5 synovial cyst	L4–5 synovial cyst resection	19	Lateral	No	256
2	Female	43	L4–5 central canal stenosis and subligamentous disc herniation	L4–5 laminotomy and undercutting for bilateral decompression L4–5 discectomy	19	Medial	No	420
3	Male	57	L3–4 lateral recess stenosis and subligamentous disc herniation	L4–5 laminotomy for stenosis and discectomy	19	Lateral and at the shoulder of the nerve root	Yes	260
4	Male	46	L4–5 disc herniation	L4–5 discectomy	19	Ventral and at the shoulder of the nerve root	Yes	149
5	Female	71	L3–5 central canal stenosis	L4 hemilaminectomy and undercutting for bilateral decompression	19	Lateral	No	200
6	Male	39	L4–5 lateral recess stenosis and L5–S1 subligamentous disc herniation	L4–5 laminotomy for stenosis and L5–S1 discectomy	15	Lateral	No	47
7	Female	48	L5–S1 lateral recess stenosis	L5–S1 laminotomy for stenosis	15	Ventral	No	119
8	Female	71	L5–S1 synovial cyst	L5–S1 synovial cyst resection	19	Lateral	Yes	211
9	Male	64	L4–5 synovial cyst	L4–5 synovial cyst resection	19	Mediolateral	Yes	220

start peeling the synovial cyst off the dura. While performing this step of the procedure the tip of the nerve hook perforated the dura. To avoid enlarging the dural tear further, the exposure of the synovial cyst was performed from more lateral to caudal. After exposing the entire cyst, again a nerve hook, a Kerrison punch and a grasper were used to peel the cyst of the dura from the caudal side to the cranial side (see Fig. 2). In the other case, the tear occurred using a Kerrison punch to peel remnant pieces of the synovial cyst off the dura.

In pure lumbar disc prolapse, the incidence of dural tear was 1.1% (1 case). The dural tear occurred at the initial stage of the procedure while performing a laminotomy; the dura and the lamina were adherent. The underlying pathology was a big lumbar subligamentous disc herniation that displaced the dural sac laterally. Once the CSF leakage was identified, the exposure of the dural tear was complicated by epidural bleeding. The flow of CSF constantly increased while the decompression of the dural sac continued and access to the subligamentous disc herniation was achieved. After the removal of the disc herniation, the pressure on the nerve root decreased rapidly and

therefore the size of the dural tear further increased which was followed by high leakage of CSF (see Fig. 3).

Dural repair

Once a dural tear occurred, the primary procedure was completed before the dural tear was treated as described below. A complete exposure to the dural tear is recommended. In case of ventral or ventrolateral dural tears complete exposure might not be feasible. At first a piece of autologous paraspinal muscle about the size of the dural tear was harvested with the Kerrison punch or a grasper. The dural tear was covered with the muscle patch which served as a buttress graft. A dissector or bayonet-shaped forceps was used to place it gently. Next a fibrin sealant patch which consist of a collagen sponge coated with human thrombin and fibrinogen (TachoSil® Takeda Pharmaceutical Company Limited, Ōsaka, Japan) was cut in small squares between 7 and 12 mm in size. A piece in proper size was moistened and then placed over with muscle covering dural tear and gently advanced with forceps or dissector until it adhered to the dura. The flow of

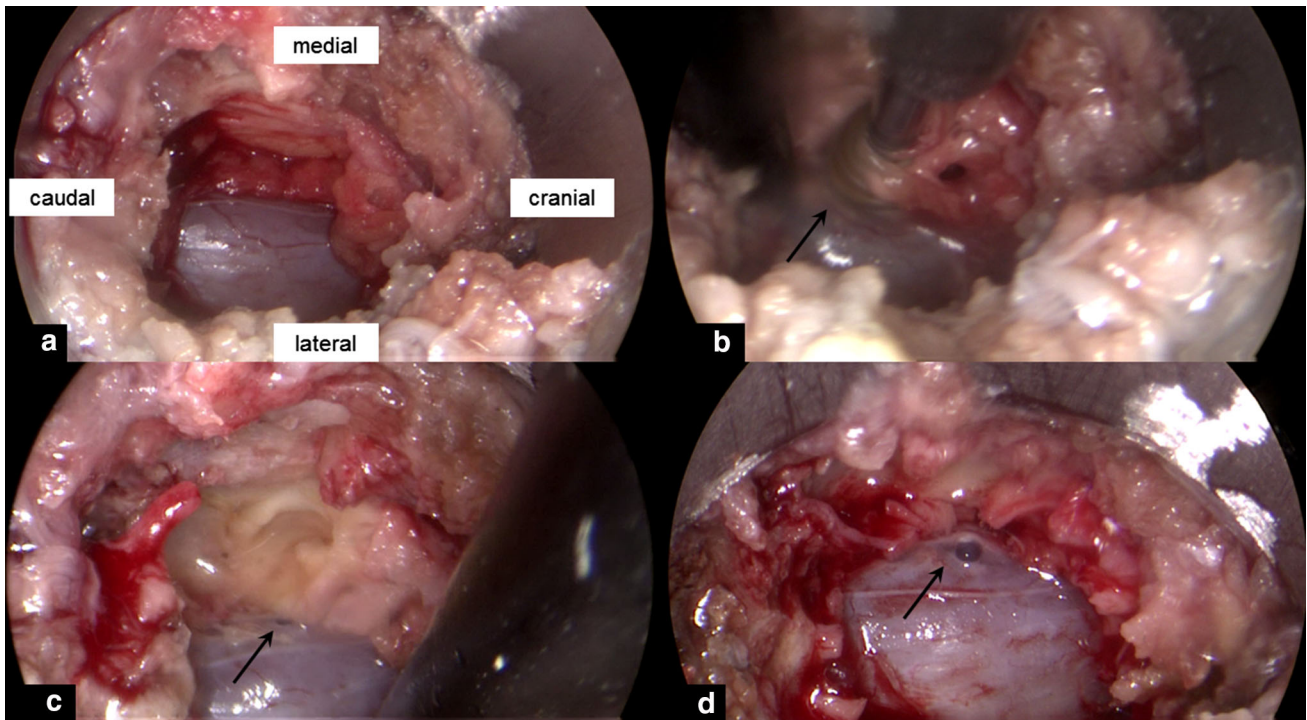


Fig. 1 Medial dural tear. **a** View onto the dura after discectomy and decompression. **b, c** Contralateral decompression with a diamond drill, the dura is teared by the tip of the diamond drill (*arrow*). **d** Exposed dural tear after further decompression

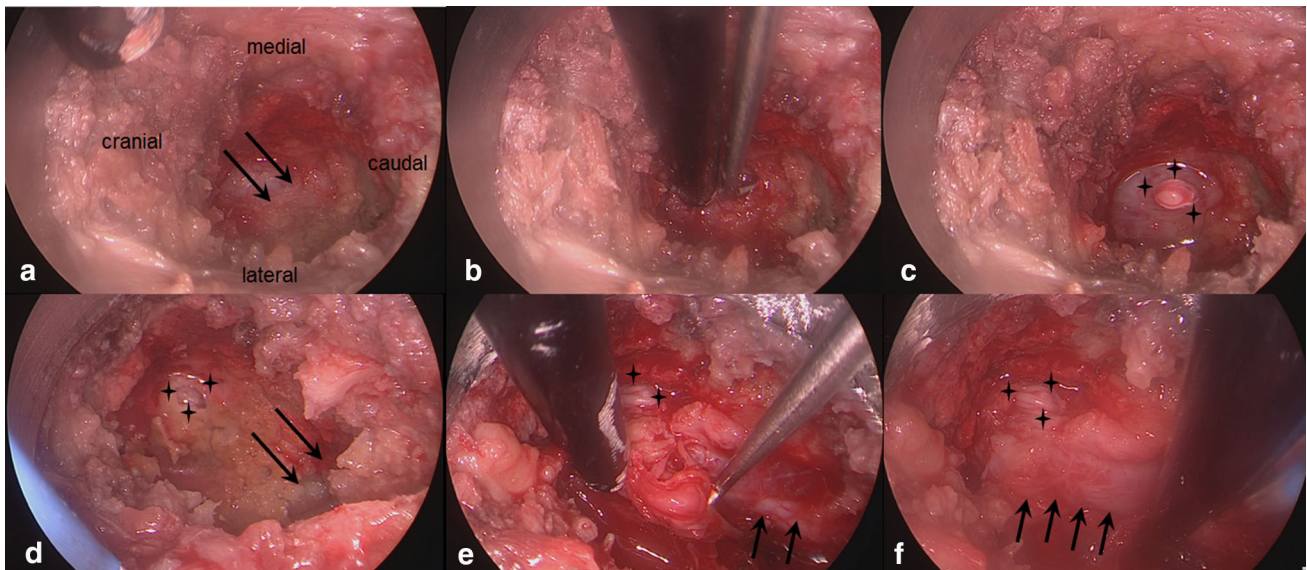


Fig. 2 Medirolateral dural tear. **a** View onto the dura and the cranial base of the synovial cyst (*arrows*). **b** Dissection of the synovial cyst be peeling it off the dura with a nerve hook. **c** Medirolateral dural tear (*stars*). **d** Exposure of the lateral and caudal base of the synovial cyst

(*arrows*), dural tear (*stars*). **e** Resection of the synovial cyst using a nerve hook, axilla of the nerve root (*arrows*). **f** Dural sac after resection of the synovial cyst, lateral aspect of the dura (*arrows*), dural tear (*stars*)

CSF is expected to considerably decrease once the surface of the fibrin sealant and the dura became adherent. Additional pieces of fibrin sealant patch were then placed to cover the brim of the initial placed fibrin sealant patch. By then the CSF flow is expected to be stopped. It might not be

feasible to cover a ventrolateral dura tear entirely. In this case the authors recommend sealing the entire lateral aspect of the dural tear and furthermore the intact dura cranially and caudally to the dura tear with several pieces. In case of a dural tear at the axilla of the nerve root a piece

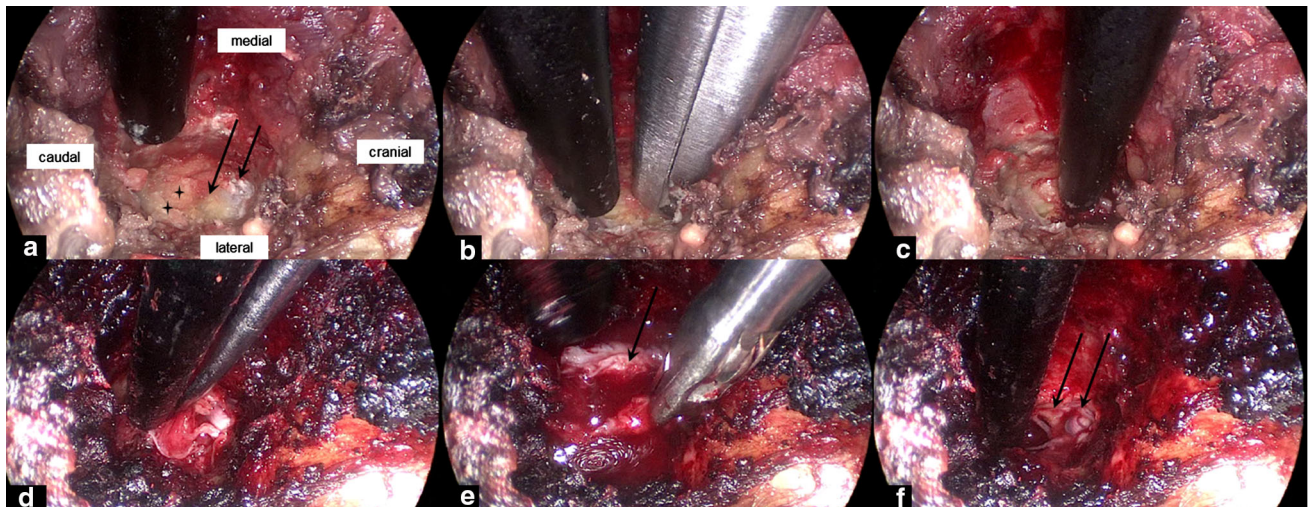


Fig. 3 Lateral dural tear. **a** View onto the surgical field after exposure of the ligamentum flavum (*stars*) and the dura (*arrows*). **b** Laminotomy with a Kerrison punch. **c** Epidural bleeding and CSF

flow. **d** Mobilization of the disc herniation after further exposure. **e** Disc herniation (*arrow*) is removed using a grasper followed by high CSF flow. **f** Dural tear with nerve fascicle herniation (*arrows*)

of collagen protein sponge (Gelita[®], Gelita AG, Eberbach, Germany) was used which served as a counter bearing to apply gentle pressure to the fibrin sealant patch. No lumbar or subfascial drains were placed. The tubular retractor was slowly removed, and meticulous hemostasis in paraspinal muscles was achieved if necessary with bipolar coagulation. Fascia was closed with interrupted 2.0 sutures. The subcutaneous tissue and the skin were closed with interrupted 3.0 sutures followed by topical skin adhesive (Dermabond[®], Ethicon Inc., Somerville, NJ, USA). An example of endoscopic dural closure after resection of a synovial cyst is shown in Video 1.

Clinical follow-up

All patients were mobilized 6 h after surgery and had a personal examination after 1, 6 and 12 weeks. Preoperatively eight patients had radicular pain, four patients had a motor deficit and two patients had a sensory deficit. At the first postoperative day all patients reported to be pain free or with improved leg pain, four patients reported an improvement in motor strength and one of the two patients with preoperative sensory deficit reported an improvement. No new neurological deficits occurred. No ongoing radicular pain or motor deficit was documented. Postoperatively no CSF fistula occurred. None of the patients had postoperative problems with wound healing or wound infection. Further none of the patients reported any kind of discomfort which could be related to the CSF leak or pseudomeningocele.

One patient who was free of pain developed a sacroiliac joint syndrome 5 months after initial procedure. The patient underwent an injection of steroid and anesthetic

mixture into the joint and was free of pain afterwards. In another patient who reported improvement of leg pain after surgery a new disc herniation occurred 4 months after initial procedure. The patient underwent repeat surgery at the adjacent segment.

Three patients underwent postoperative MRI to confirm complete resection of synovial cyst. In all cases there was no evidence of a CSF fistula, no nerve root tethering, no dural sac compression and no pseudomeningocele (see Fig. 4).

Discussion

At the initial stages of endoscopic spinal surgery, concerns have been raised that endoscopic techniques might cause higher incidence of dural tears than in open surgery because of poor image quality and depth perception [16]. The criticism was refuted by several studies which reported better tissue identification via HD endoscopy a similar rate of dural tear for conventional and endoscopic lumbar spinal surgery [17–20]. In the present study the rate of dural tear in cases of lumbar disc herniation and lumbar canal stenosis was in line with previously reported numbers in standard open procedure or tubular-assisted procedures [2, 11, 21, 22].

However, the incidence of dural tear in the present study was considerably higher (i.e. 37.5%) compared to cases of lumbar disc herniation or lumbar stenosis. One reason for this high dural tear rate might be the limited instrument workability of the endoscopic tubular-assisted procedure. A greater outer diameter of the tubular retractor might be useful in the dissection of a very adhesive synovial cyst and to reduce the rate of dural tears.

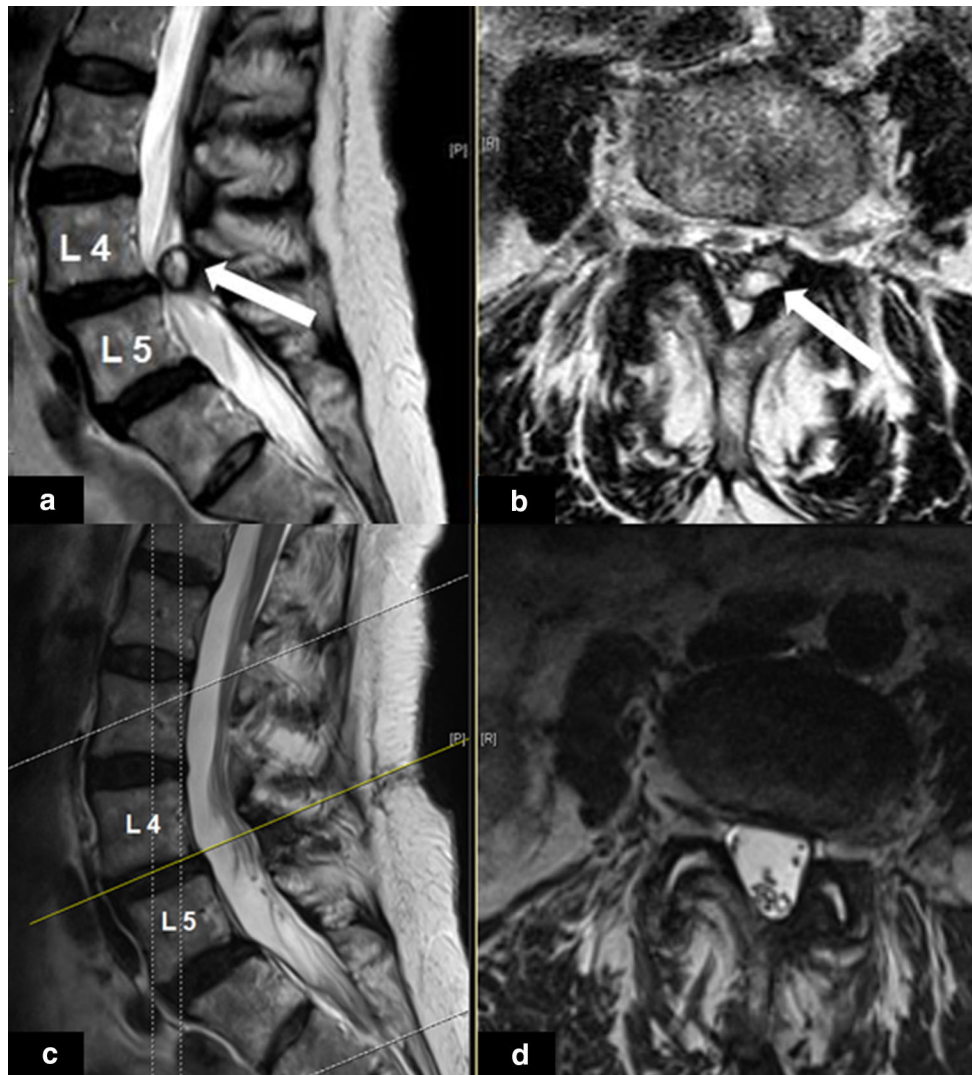


Fig. 4 Preoperative and postoperative MRI. **a, b** Preoperative parasagittal and axial MRI of a synovial cyst (*white arrow*). **c, d** Postoperative parasagittal and axial MRI after complete resection of

the synovial cyst with decompressed dural sac. No signs of and no CSF collection, and no signs of compression of the dural sac

Once a serious complication occurs, the surgical procedure may be no longer minimally invasive. Clinical outcome in a long-term seems to be worse in cases with dural injury compared to those without the occurrence of dural injury [21]. Some authors believe that it is inevitable to repair the dural tear to prevent the occurrence of a pseudomeningocele or even spinal fluid leak that other surgeons do not feel that to repair a dural tear in tubular-assisted surgery is generally necessary because of the minimal dead space [3, 23]. Till today there is no clear evidence for that kind of arguing and even in percutaneous and tubular-assisted surgery with very minimal death space, an unrecognized dural tear might be followed by repeat surgery and repair of a pseudomeningocele [8, 24]. Therefore the authors recommend dural closure even in procedures via muscle splitting approach.

In minimally invasive spine surgery, direct repair via suturing is not always feasible due to inaccessible location of dural tear and limited working space. Operating through a small working tube may not allow the manipulation of instruments as accustomed in conventional surgery which could then force the surgeon to convert the procedure to open surgery. A case report of primary dural repair through an 18 mm tubular retractor using pituitary instruments has been first described by Chou et al. in 2009 [6].

In 2011, Ruban et al. reported good result of dural repair via suturing which was followed with the application of fibrin glue and patients were kept in bed rest overnight. However, the outer diameter of the tubular retractor in this series has been reported to be 22–26 mm with an option to expand it up to 40 mm [11]. To the best of the authors' knowledge there is no series of patients with primary

suturing through a tubular retractor with 18 mm or less in outer diameter.

In the present series the outer diameter was considerably smaller (15–19 mm) and the procedure was performed under endoscopic visualization. It remains unclear if direct dural repair via suturing could be performed under endoscopic or microscopic visualization view through a 15–19 mm tubular retractor at the same time as dural closure was performed with the described technique. Dural repair without direct suturing is a well-known technique in conventional spine surgery and about 80% of spine surgeons reported good experience with this technique [13].

The U-clip was originally designed to tie abdominal vessels and fascia endoscopically. Spine surgeons used this self-closing device in combination with fibrin glue for dural repair in tubular-assisted spinal surgery [25]. However, the disadvantage of the U-clip is that the needle has to be passed with an instrument similar to suturing before the surgeon is confronted with the unfamiliar release mechanism. Dural closure without suturing via augmentation (i.e. fat graft, collagen matrix, fibrin glue, U-clip etc.) is commonly performed in tubular-assisted surgery. The authors believe that the decreased dead space is an important benefit of the muscle splitting approach because it reduces the space for CSF accumulation and formation of a pseudomeningocele.

Postoperative immobilization due to bed rest is associated with a prolonged hospital stay, the risk of postoperative complications such as deep venous thrombosis, infection and additional costs. The goal therefore should be to close the dural tear in a way that allows early mobilization. To the best of the authors' knowledge there are a few reports that described the closure of a dural tear through a tubular retractor without suturing in detail. In those reports the patients were put in bed rest and the presented technique of dural repair was not consistent [7]. Shibayama et al. reported about seven patients with incidental dural tear. In all cases dural repair was successfully performed without suturing by applying a polyglactin sheet that was soaked in fibrinogen and patients were mobilized at the second postoperative day [5].

This manuscript was not meant to persuade other spine surgeons that the endoscopic visualization is the golden standard. The authors are very experienced in endoscopic spinal surgery and favour the endoscopic HD visualization over the microscopic visualization because in their experience under endoscopic visualization the surgical field does not get obstructed by the shaft of the surgical instrument. Even though the authors have never performed this technique of dural closure under microscopic visualization or under magnification via loupe, the authors are convinced that this technique offers the same result as long as a tubular retractor and muscle splitting approach is used

for procedure. The authors are of the opinion that dural closure through a tubular retractor should be safe, fast and easy to learn. The angled 30° endoscopic optic offers ideal visualization of the surgical field. The position of the endoscope is adjustable and therefore allows for inspection of remote corner of the surgical field which is very helpful. In the present study the average time for dural closure was 209 s and no intraoperative complication occurred while dural repair. All patients were mobilized 6 h postoperatively and no cutaneous CSF fistula or symptoms that could be related to CSF fistula were noted. Further, all postoperative MRI showed no evidence of CSF fistula or nerve root tethering in patients.

Conclusions

Dural closure with a combination of an autologous muscle graft and a fibrin sealant patch is may be a fast, safe and alternative technique for the management of dural tear in endoscopic tubular-assisted spinal surgery.

Compliance with ethical standards

Conflict of interest J. Oertel and B. Burkhardt have no conflict of interest.

Funding None.

Disclosure J. Oertel is a consultant to the Karl Storz Company.

References

1. He J, Xiao S, Wu Z, Yuan Z (2016) Microendoscopic discectomy versus open discectomy for lumbar disc herniation: a meta-analysis. *Eur Spine J* 25(5):1373–1381. doi:[10.1007/s00586-016-4523-3](https://doi.org/10.1007/s00586-016-4523-3)
2. Stromqvist F, Jonsson B, Stromqvist B, Swedish Society of Spinal S (2010) Dural lesions in lumbar disc herniation surgery: incidence, risk factors, and outcome. *Eur Spine J* 19(3):439–442. doi:[10.1007/s00586-009-1236-x](https://doi.org/10.1007/s00586-009-1236-x)
3. Guerin P, El Fegoun AB, Obeid I, Gille O, Lelong L, Luc S, Bourghli A, Cursolle JC, Pointillart V, Vital JM (2012) Incidental durotomy during spine surgery: incidence, management and complications. A retrospective review. *Injury* 43(4):397–401. doi:[10.1016/j.injury.2010.12.014](https://doi.org/10.1016/j.injury.2010.12.014)
4. Tafazal SI, Sell PJ (2005) Incidental durotomy in lumbar spine surgery: incidence and management. *Eur Spine J* 14(3):287–290. doi:[10.1007/s00586-004-0821-2](https://doi.org/10.1007/s00586-004-0821-2)
5. Shibayama M, Mizutani J, Takahashi I, Nagao S, Ohta H, Otsuka T (2008) Patch technique for repair of a dural tear in microendoscopic spinal surgery. *J Bone Jt Surg Brit* 90(8):1066–1067. doi:[10.1302/0301-620X.90B8.20938](https://doi.org/10.1302/0301-620X.90B8.20938)
6. Chou D, Wang VY, Khan AS (2009) Primary dural repair during minimally invasive microdiscectomy using standard operating room instruments. *Neurosurgery* 64(5 Suppl 2):356–358. doi:[10.1227/01.NEU.0000338942.11337.DA](https://doi.org/10.1227/01.NEU.0000338942.11337.DA) (discussion 358–359)

7. Than KD, Wang AC, Etame AB, La Marca F, Park P (2008) Postoperative management of incidental durotomy in minimally invasive lumbar spinal surgery. *Minim Invas Neurosurg* 51(5):263–266. doi:[10.1055/s-0028-1082313](https://doi.org/10.1055/s-0028-1082313)
8. Ahn Y, Lee HY, Lee SH, Lee JH (2011) Dural tears in percutaneous endoscopic lumbar discectomy. *Eur Spine J* 20(1):58–64. doi:[10.1007/s00586-010-1493-8](https://doi.org/10.1007/s00586-010-1493-8)
9. Wu X, Zhuang S, Mao Z, Chen H (2006) Microendoscopic discectomy for lumbar disc herniation: surgical technique and outcome in 873 consecutive cases. *Spine* 31(23):2689–2694. doi:[10.1097/01.brs.0000244615.43199.07](https://doi.org/10.1097/01.brs.0000244615.43199.07)
10. Tsutsumimoto T, Yui M, Uehara M, Ohta H, Kosaku H, Misawa H (2014) A prospective study of the incidence and outcomes of incidental dural tears in microendoscopic lumbar decompressive surgery. *Bone Jt J* 96-B(5):641–645. doi:[10.1302/0301-620X.96B5.32957](https://doi.org/10.1302/0301-620X.96B5.32957)
11. Ruban D, O’Toole JE (2011) Management of incidental durotomy in minimally invasive spine surgery. *Neurosurg Focus* 31(4):E15. doi:[10.3171/2011.7.FOCUS11122](https://doi.org/10.3171/2011.7.FOCUS11122)
12. Tan LA, Takagi I, Straus D, O’Toole JE (2014) Management of intended durotomy in minimally invasive intradural spine surgery: clinical article. *J Neurosurg Spine* 21(2):279–285. doi:[10.3171/2014.3.SPINE13719](https://doi.org/10.3171/2014.3.SPINE13719)
13. Gautschi OP, Stienen MN, Smoll NR, Corniola MV, Tessitore E, Schaller K (2014) Incidental durotomy in lumbar spine surgery—a three-nation survey to evaluate its management. *Acta Neurochir (Wien)* 156(9):1813–1820. doi:[10.1007/s00701-014-2177-7](https://doi.org/10.1007/s00701-014-2177-7)
14. Oertel JM, Mondorf Y, Gaab MR (2009) A new endoscopic spine system: the first results with “Easy GO”. *Acta Neurochir* 151(9):1027–1033. doi:[10.1007/s00701-009-0454-7](https://doi.org/10.1007/s00701-009-0454-7)
15. Oertel JM, Philipps M, Burkhardt BW (2016) Endoscopic posterior cervical foraminotomy as a treatment for osseous foraminal stenosis. *World Neurosurg* 91:50–57. doi:[10.1016/j.wneu.2016.02.073](https://doi.org/10.1016/j.wneu.2016.02.073)
16. Teli M, Lovi A, Brayda-Bruno M, Zagra A, Corriero A, Giudici F, Minoia L (2010) Higher risk of dural tears and recurrent herniation with lumbar micro-endoscopic discectomy. *Eur Spine J* 19(3):443–450. doi:[10.1007/s00586-010-1290-4](https://doi.org/10.1007/s00586-010-1290-4)
17. Quigley MR, Bost J, Maroon JC, Elrifai A, Panahandeh M (1998) Outcome after microdiscectomy: results of a prospective single institutional study. *Surg Neurol* 49(3):263–267 (**discussion 267–268**)
18. Daneyemez M, Sali A, Kahraman S, Beduk A, Seber N (1999) Outcome analyses in 1072 surgically treated lumbar disc herniations. *Minim Invas Neurosurg* 42(2):63–68. doi:[10.1055/s-2008-1053372](https://doi.org/10.1055/s-2008-1053372)
19. Nohara Y, Taneichi H, Ueyama K, Kawahara N, Shiba K, Tokuhashi Y, Tani T, Nakahara S, Iida T (2004) Nationwide survey on complications of spine surgery in Japan. *J Orthop Sci* 9(5):424–433. doi:[10.1007/s00776-004-0802-7](https://doi.org/10.1007/s00776-004-0802-7)
20. Philipps M, Oertel J (2010) High-definition imaging in spinal neuroendoscopy. *Minim Invas Neurosurg* 53(3):142–146. doi:[10.1055/s-0030-1262811](https://doi.org/10.1055/s-0030-1262811)
21. Saxler G, Kramer J, Barden B, Kurt A, Pfortner J, Bernsmann K (2005) The long-term clinical sequelae of incidental durotomy in lumbar disc surgery. *Spine* 30(20):2298–2302
22. Khan MH, Rihn J, Steele G, Davis R, Donaldson WF 3rd, Kang JD, Lee JY (2006) Postoperative management protocol for incidental dural tears during degenerative lumbar spine surgery: a review of 3183 consecutive degenerative lumbar cases. *Spine* 31(22):2609–2613. doi:[10.1097/01.brs.0000241066.55849.41](https://doi.org/10.1097/01.brs.0000241066.55849.41)
23. Epstein NE (2013) A review article on the diagnosis and treatment of cerebrospinal fluid fistulas and dural tears occurring during spinal surgery. *Surg Neurol Int* 4(Suppl 5):S301–S317. doi:[10.4103/2152-7806.111427](https://doi.org/10.4103/2152-7806.111427)
24. Palmer S, Davison L (2012) Minimally invasive surgical treatment of lumbar spinal stenosis: two-year follow-up in 54 patients. *Surg Neurol Int* 3:41. doi:[10.4103/2152-7806.94294](https://doi.org/10.4103/2152-7806.94294)
25. Park P, Leveque JC, La Marca F, Sullivan SE (2010) Dural closure using the U-clip in minimally invasive spinal tumor resection. *J Spinal Disord Tech* 23(7):486–489. doi:[10.1097/BSD.0b013e3181c7e901](https://doi.org/10.1097/BSD.0b013e3181c7e901)