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Complications of Biportal Endoscopic Surgery for Lumbar Pathologies: Retrospective Analysis of 374 Cases

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ABSTRACT

AIM: To evaluate the complications associated with Unilateral Biportal Endoscopy (UBE) in spinal surgery, highlighting the risks and outcomes of this minimally invasive approach.

MATERIAL and METHODS: A retrospective analysis was conducted on 374 patients who underwent UBE at three centers from 2022 to 2023. The study included cases of lumbar disc herniation, recurrent disc herniation, and lumbar stenosis. All procedures were performed by experienced surgeons, with a minimum postoperative follow-up of one year for each patient.

RESULTS: A total of 374 patients were included: 224 underwent UBE discectomy, 115 underwent UBE decompression for lumbar stenosis, and 35 underwent surgery for recurrent herniation. Overall, 178 patients (47.5%) were female and 196 (52.4%) were male. Complication rates differed across cohorts: 19 complications occurred in primary discectomy cases (8.4%), 12 in stenosis cases (10.4%), and 5 in recurrent cases (14.2%). The most common complications were dural tear (n=8), recurrence (n=7), and root injury (n=6). Less frequent events included retinal hemorrhage (n=2) and hydroperitoneum (n=1).

CONCLUSION: The findings suggest that while UBE is generally safe, it is associated with a notable complication rate, including dural tears and root injuries. Continuous efforts to refine surgical techniques and enhance training may further mitigate these risks, ensuring better patient outcomes.

KEYWORDS: Unilateral biportal endoscopic surgery, Lumbar disc herniantion, Complication, Spinal stenosis, Dural tear, Neural injury

ABBREVIATIONS: ACS: Abdominal compartment syndrome, **CSF:** Cerebrospinal fluid, **IAP:** Inferior articular process, **RF:** Radiofrequency, **SF:** Saline fluid, **SAP:** Superior articular process, **UBE:** Unilateral biportal endoscopy

INTRODUCTION

Minimally invasive approaches are becoming widespread in spinal surgery as in every surgical discipline. In spinal surgery, after Kambin described transforaminal monoportal endoscopic discectomy in 1986, De antoni et al described biportal endoscopic discectomy in 1996 (6,11). In this minimally invasive surgery performed through two separate skin incisions, the endoscope is inserted through one portal while the working instruments are inserted through the other. While it has the advantages of no muscle stripping, small skin incisions, less infection and less bleeding with saline irrigation as in monoportal surgeries, it offers a wider range of motion, although not as much as in microsurgery, since the viewing and working ports are separate. In this way, we can define it as a hybrid surgery that takes the advantages of microsurgery and monoportal minimally inva-

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sive surgery (25). It may be an alternative to microsurgery, the gold standard defined by Yasargil (31).

While UBE surgery offers advantages in minimally invasive spine procedures, it is not without potential complications. The most commonly reported complications include dural tears, which can lead to CSF leakage and associated headaches, and epidural hemorrhages, which may necessitate further intervention if they compromise neural elements. Root injuries are another significant risk, potentially resulting in sensory or motor deficits. Infection, although infrequent, remains a concern, as does CSF fistula formation in cases involving dural injury. Insufficient decompression and residual instability may necessitate additional surgeries, particularly in cases of severe stenosis or instability-prone patients. Recurrence of pathology, such as herniated discs, can also lead to repeat procedures. Less common but serious complications include retinal hemorrhage, possibly due to intraoperative positional factors, and abdominal compartment syndrome, which may arise from prolonged prone positioning or high irrigation pressures. These risks underscore the importance of meticulous technique and preoperative planning to minimize the likelihood of adverse outcomes. In this study, we present the complications observed in patients who underwent surgery using the UBE method, along with their statistical incidence. The precautions taken to prevent postoperative complications were discussed in the accompaniment of the literature.

MATERIAL and METHODS

This observational study was conducted retrospectively using anonymized patient data, approved by Institutional Review Board with E1-23-3357 and car-ried out in accordance with the principles of the Declaration of Helsinki.

This was a retrospective study including patients who underwent unilateral biportal endoscopic (UBE) lumbar surgery between January 2022 and December 2023. A total of 406 patients were initially identified. Thirty-two patients were excluded due to loss to follow-up, leaving 374 patients for analysis. All patients were operated between January 2022 and December 2023, and their postoperative follow-up has continued from January 2024 to the present, ensuring that each included patient has achieved at least one year of follow-up.

Inclusion criteria were patients with symptomatic lumbar disc herniation (LDH), recurrent lumbar disc herniation, or lumbar spinal stenosis who were refractory to conservative management and underwent UBE surgery. Exclusion criteria included far lateral disc herniations and percutaneous posterior fusion cases, due to insufficient case numbers.

All surgeries were performed by senior spine surgeons, each of whom had at least five years of general spine surgery experience and had independently adopted UBE prior to the study period.

Follow-up protocol: Patients were routinely evaluated at postoperative day 10, postoperative month 1, and postoperative year 1, including clinical examination and MRI if recurrent symptoms were suspected.

Surgical Technique

The procedure was performed using a 30°, 4 mm rigid arthroscope, 4 mm spherical burr (Stryker), 3.5 mm radiofrequency (RF) ablation probe (Stryker) and standard microdiscectomy (kerrison, nerve hook, etc.). Under general anesthesia, in the prone position, C-arm fluoroscopy was used for distance determination and triangulation for the target level. In triangulation, a 5 mm transverse incision in the cranial pedicle (viewing portal) and a 9 mm transverse incision in the caudal pedicle (working portal) target the lower endplate of the vertebra cranial to the pathologic distance. During both incisions, the scalpel is slightly tilted to coincide with the target end-plate. Both incisions are made approximately 0.5-1cm laterally, closest to the median line. In left-sided surgeries for right-handed dominant surgeons, the trocar through the upper incision and dilators placed sequentially through the lower incision meet at the lower end of the target lamina. For right-sided pathologies, the surgeon positions themselves on the right side of the patient, planning the incision so that the imaging portal is oriented caudally. Alternatively, the imaging portal may be positioned cranially, allowing the surgeon to operate with their left hand. Room-temperature saline solutions were preferred for irrigation. This approach prevented hypothermia caused by excessively cold solutions and avoided increased bleeding associated with warm solutions. For gravity-assisted irrigation, sterile saline solution is suspended 50 cm above the patient's spine. If available, a pressure-controlled irrigation device may also be utilized from the hospital inventory. Automatic pumps were not available in any of the three centers where the study was conducted; therefore, pressure values were not monitored. However, in cases where an obstruction occurred in the saline outflow, irrigation was stopped until the outflow was restored, preventing epidural pressure from reaching dangerous levels. Once irrigation is initiated, anatomical landmarks, including the lamina, spinous process base, inferior articular process (IAP), and interlaminar ligamentum flavum are identified. The soft tissues overlying these structures, including the multifidus muscle, are removed using an RF probe and forceps. Based on the planned procedure, laminectomy and inferior and superior facetectomy are performed with the aid of a high-speed burr or Kerrison rongeur. Subsequently, flavectomy and, if necessary, discectomy are completed to finalize the procedure. In cases of narrow spinal canals, the base of the spinous process is drilled, and foraminotomy is achieved through contralateral facetectomy and sublaminar flavectomy. In recurrent cases, the IAP and superior articular process (SAP) of the target distance and scar tissue are dissected to reach the disc space and discectomy is performed.

RESULTS

A total of 374 patients were included, consisting of 178 females and 196 males. The mean age was 47.3 years (range, 18–75 years). Surgical indications included 224 lumbar disc herniations (59.9%), 115 lumbar stenosis cases (30.7%), and 35 recurrent disc herniations (9.3%).

Complications occurred in 36 patients (9.6%). The most frequent complications were dural tear (n=8, 2.1%), recurrent disc herniation (n=7, 1.9%), and root injury (n=6, 1.6%). Less common but unique to endoscopic irrigation were retinal hemorrhage (n=2, 0.5%) and hydroperitoneum/abdominal compartment syndrome (n=1, 0.3%). Other complications included infection (n=4, 1.1%), inadequate decompression (n=5, 1.3%), instability (n=2, 0.5%), and epidural hematoma (n=1, 0.3%). No cerebrospinal fluid (CSF) fistula was observed.

Learning curve analysis: While the incidence of dural tears and recurrences did not differ significantly between early and later cases (as UBE closely resembles microsurgical techniques once triangulation is completed), both retinal hemorrhage and abdominal compartment syndrome (ACS) occurred within the first 100 surgeries during the initial learning-curve period. No cases of ACS, blurred vision, or retinal complications were observed thereafter.

A detailed distribution of complications by procedure type is provided in Table I.

DISCUSSION

In our case series, the complication rates observed were consistent with those reported in the literature (5,7,20,21,27). Notably, our data included recurrent cases, a patient-specific risk factor. Based on these findings, we reviewed the complications encountered and the preventive measures implemented, supported by relevant literature. Additionally, we outlined strategies developed during the study to minimize complications, informed by our growing experience.

Dural Tear

A total of 8 cases (2.1%) of dural tears were observed in our series. Of these, 2 occurred during endoscopic lumbar discectomy, 5 during biportal endoscopic lumbar spinal stenosis surgery, and 1 during biportal endoscopic revision surgery. Dural tears are a particularly common complication in spinal stenosis surgery, with a reported incidence of 8.6% in the literature (1,27). Notably, 5 of the 8 dural tears (62.5%) occurred during spinal stenosis procedures. The literature has reported that dural tears are observed during the use of osteotomes, curettes, Kerrison punches for decompression, burr devices during contralateral decompression, and pituitary forceps for epidural fat excision (27). In our series, all dural tears occurred during the use of the Kerrison punch, which may be related to its preference over other instruments such as burr, curette, or forceps during decompression. Considering the risk of dural injury increases in cases of severe stenosis where adhesions between the dura and ligamentum flavum or the presence of the dorsal meningovertebral ligament, one way to reduce the incidence of this complication is to ensure that neural structures are not inadvertently excised along with the tissue being decompressed (epidural fat, ligamentum flavum) when using the Kerrison rongeur. Another preventive measure could be to avoid using Kerrison punches that have lost their sharpness, as deformed punches that tear rather than cleanly cut the flavum can increase the risk of dural tears. Dural tears resulting from burr or osteotome use are typically not large. Moreover, due to the minimal muscle, fascia, and skin defects in biportal endoscopic spinal surgery, cerebrospinal fluid (CSF) fistulas are uncommon, as none of the patients with dural tears in this study developed a CSF fistula. Fibrin sealant patches were not applied in any of the tear cases. In a study by Park et al., dural tears smaller than 4 mm in patients operated on using the biportal endoscopic technique were managed conservatively, while tears between 4 and 12 mm were treated with fibrin sealant patches, and for tears larger than 12 mm, endoscopic or microscopic primary suturing was recommended (27). Similarly, in the study by Ozer et al., an approximately 8 mm durotomy in a patient with tethered cord syndrome operated on using the biportal endoscopic approach was successfully managed conservatively without fibrin sealant or primary suturing, with no CSF fistula or pseudomeningocele reported (26). Conservative management may include close neurological monitoring and 24-hour immobilization bed rest. In cases

Table I: Complications of Unilateral Biportal Endoscopic Surgery (UBE)

	Discectomy	Spinal Stenosis	Recurrent Surgery	Total
Operation Count, n	224	115	35	374
Complicated Case Count, n (%)	19 (8.4)	12 (10.4)	5 (14.2)	36 (9.6)
Dural Tear, n	2	5	1	8
Epidural Hemorrhage, n	-	1	-	1
Root Injury, n	3	1	2	6
Infection, n	3	-	1	4
CSF Fistula, n	-	-	-	-
Insufficient decompression, n	2	3	-	5
Instability, n	-	1	1	2
Recurrence, n	7	-	-	7
Retinal hemorrhage, n	2	-	-	2
Abdominal Compartment Syndrome, n	-	1	-	1

CSF: *Cerebrospinal fluid,* ***UBE:*** *Unilateral biportal endoscopic surgery*

where pseudomeningocele is likely to develop, endoscopic or microscopic dural repair can be performed (Figure 1).

Epidural Hemorrhage

In this study, a hematoma that could lead to postoperative neurological deficits following decompressive surgery for lumbar spinal stenosis was observed in only 1 (0.3%) case. According to Sokolowski et al., radiological epidural hemorrhage occurs in approximately 58% of patients undergoing lumbar decompression surgery (29). However, a very small percentage of this population (0.02% to 4.6%) develops symptomatic hematomas, which may necessitate additional surgical intervention (2,29). In a study by Kim et al., of 310 patients treated via biportal endoscopic surgery, 23% had radiologically observed epidural hemorrhage (14). Although this incidence is relatively low compared to microscopic surgery, 56 patients required a thrombin-containing hemostatic agent (Floseal [Baxter International Inc., Deerfield, Illinois, USA]). Additionally, a drain was placed in each patient and was removed after 1 or 2 days. Female sex, older age (>70 years), preoperative anticoagulation therapy, and the use of an intraoperative water infusion pump were identified as the primary risk factors for hemorrhage in their study (14). Consistent with the literature, in our practice, we used a drain for 12 hours in elderly patients on anticoagulation/antiplatelet therapy. Water infusion pumps and thrombin-based hemostatic agents were not utilized. We suggest that the use of drains in elderly patients with a tendency for bleeding and significant intraoperative hemorrhage may prevent this complication. In cases where the epidural hematoma resulted in deficits, hematoma evacuation was performed using the biportal endoscopic technique. We believe that early intervention in cases presenting neurological deficits (such as cauda equina syndrome or mild neurological deterioration) may prevent irreversible deficits. The literature also suggests that mild symptoms may resolve due to spontaneous hematoma resorption by the third postoperative week (9).

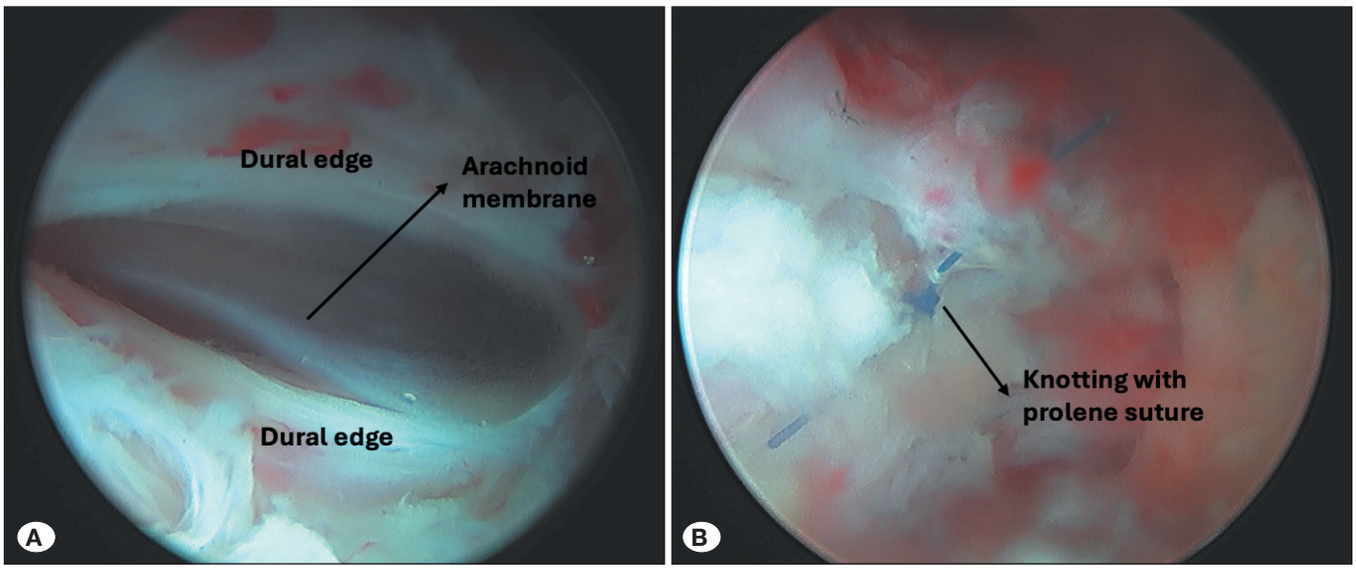

Figure 1: Dural tear. **A)** Example of a case with a dural tear. **B)** Image of the closed tear after suturing.

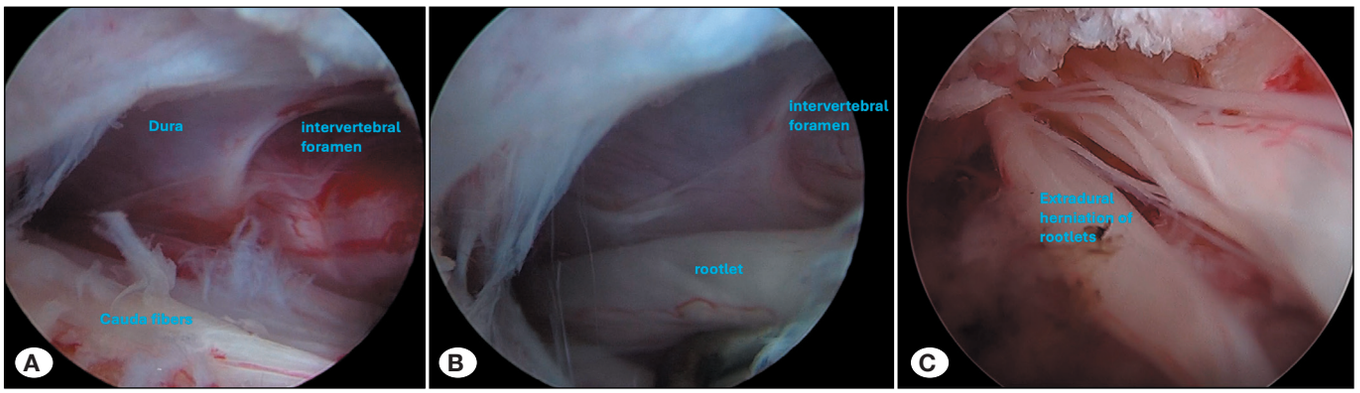

Figure 2: Root Injury Example. **A)** Image of the intrathecal area after neural injury, showing cauda equina fibers and the view of the intervertebral foramen from within the dura. **B)** The rootlet seen intradurally, entering the intervertebral foramen. **C)** In a recurrent case, herniation of the rootlets into the extradural space is observed during fragmentectomy.

Nerve Root Injury

A total of 6 cases (1.6%) were observed. The distribution included 3 cases in endoscopic lumbar discectomy, 1 case in biportal endoscopic lumbar spinal stenosis surgery, and 2 cases in biportal endoscopic revision surgery (Figure 2). According to the literature, the primary cause of root injuries is often thermal damage due to the use of radiofrequency (RF) devices (21). Cauterization of epidural veins/arteries, particularly those coursing toward the foramen, can be challenging, and controlling bleeding in these areas may pose significant risks. In lumbar decompression for spinal stenosis, high-speed motor or osteotome usage may contribute to such injuries. In revision cases, root injuries may also occur due to adhesions that form, especially when scar tissue or disc material is excised using pituitary forceps. Minimizing RF power and using it for short durations can reduce the frequency of these injuries (20). In decompression for spinal stenosis, performing a laminectomy/foraminotomy prior to flavectomy and using the ligamentum flavum as a protective barrier is a prudent approach. In revision cases, dissection should proceed by carefully isolating the superior articular process from epidural fibrosis; if necessary, access to the disc space can then be achieved by partially excising the superior articular process laterally to the root. This approach reduces the risk of accidental root injury due to loss of orientation or inadvertent compression with pituitary forceps. Since disc material may be adherent, attempting discectomy with large pituitary forceps in a single pass should be avoided. Instead, extruded or sequestered fragments should be gently mobilized using a nerve hook or smaller forceps to ensure neural structures are not inadvertently engaged. Controlled removal of the disc material in this way lowers the risk associated with discectomy in complex cases.

Infection

Four cases (1.1%) were detected, three of which occurred during endoscopic lumbar discectomy and one during biportal endoscopic revision surgery (Figure 3). While saline irrigation can reduce the risk of infection, the literature reports an incidence rate of 0.1% to 4.5% (10,18). Although our series reflects a rate consistent with the literature, we believe that the risk could dramatically decrease in cases without significant comorbidities such as diabetes mellitus and immunodeficiency with proper antisepsis. We advocate for the use of a gas plasma sterilization system (low-temperature sterilization of plastic and electrical instruments) instead of rapid disinfection methods like ortho-phthalaldehyde. If a paravertebral abscess or diskitis occurs, disc needle biopsy by fluoroscopy may be necessary to sample the pathogen if it has not fistulized to the skin. If conservative treatments are insufficient, surgical intervention for debridement may be required (10).

Insufficient Decompression

There were 5 cases (1.3%) of insufficient decompression observed, with 2 cases in endoscopic lumbar discectomy and 3 cases in biportal endoscopic lumbar spinal stenosis surgery. In the literature, overlooked migrated fragments in cases of disc herniation and insufficient decompression in cases with severe stenosis are reported, especially during the initial stages of a surgeon's learning curve (5,10,20). In inferiorly migrated disc fragments, residual fragments may remain if they do not come out in a single piece. The wide range of motion in UBE, unlike monoportal techniques, allows for a more aggressive residual check (25). Increasing decompression and using a nerve hook through the axilla to search for inferiorly migrated fragments may be beneficial; however, manipulating the axilla often leads to bleeding, and this approach is not always feasible due to the risk of root or dural injury. In spinal stenosis surgeries, insufficient resection of the proximal and contralateral ligamentum flavum is typically reported (5). The use of a foraminal Kerrison rongeur or an angled curette can facilitate a more effective flavectomy. For the contralateral side, drilling the base of the spinous process may allow better access for instruments and the endoscope. For adequate foraminal decompression, the medial wall of the bilateral pedicles should be visualized. The return of dural pulsation should be checked to ensure sufficient decompression (20). Additionally, blurred vision is a major cause of incomplete decompression. Maintaining systolic blood pressure below 100 mmHg and applying bone wax and Gelfoam® (absorbable gelatin sponge, USP) can help prevent the "red screen" effect on the endoscope.

Instability

A total of 2 cases (0.5%) of instability were observed, with one occurring during biportal endoscopic lumbar spinal stenosis surgery and the other during biportal endoscopic revision surgery. Biomechanical studies suggest that laminectomies compromising more than 50% of the pars interarticularis increase the risk of iatrogenic instability (20). Excessive drilling of the inferior articular process and extensive laminectomy are

Figure 3: Contrast-enhanced T1 MRI of a patient who developed an infection after UBE surgery.

known risk factors for this complication. Although minimally invasive surgeries reduce these risks, they do not entirely eliminate them. In the study by Kim et al., iatrogenic instability occurred in 0.6% of patients following UBE surgery, significantly lower than in microsurgery (reported between 3.96% and 9.5%) due to the lack of muscle dissection and the preservation of facet joints (16). In this study, complication rates were consistent with the literature. To mitigate the risk of iatrogenic instability, the use of a 30-degree endoscope and a foraminal Kerrison rongeur or curved curette to minimize the extent of laminectomy may be beneficial, along with partial resection of the superior articular process without compromising the integrity of the inferior articular process where feasible.

Recurrence

A total of 7 cases (1.9%) of recurrence were observed, all occurring during endoscopic lumbar discectomy. Despite the high success rate of surgical treatment for lumbar disc herniation (LDH), recurrence may still occur in 15-25% of cases (12). Reoperation is indicated in approximately 62% of recurrent disc herniations (12). Recurrent lumbar disc herniation (RLDH) is defined as the recurrence of herniation at the same level and on the same side following a pain-free interval of at least six months post-surgery (10). This condition should be distinguished from residual or insufficient decompression. RLDH is often associated with aging, improper lifting techniques, and risk factors including male gender, obesity (BMI ≥ 25 kg/m^2), advanced age (≥ 50 years), trauma history, and central disc herniation (10). Additionally, for minimally invasive procedures, surgeon inexperience poses an added risk factor for recurrence. Surgeon-related factors, such as insufficient decompression, large posterior longitudinal ligament defects, excessive laminectomy or facetectomy, and extensive muscle dissection, can also contribute to recurrence. Postoperative guidelines, including lumbar muscle exercises, avoidance of heavy lifting, and maintaining proper posture, are crucial for reducing the risk of LDH recurrence. The recurrence rate in our study was relatively low (1.9%). This outcome may be influenced by the shorter follow-up period inherent in studies of UBE, a relatively novel surgical technique. It is anticipated that with longer follow-up durations, such as 5 or 10 years, the recurrence rate could increase, potentially aligning more closely with rates reported in the literature for other established techniques.

Retinal Hemorrhage

Retinal hemorrhage was observed in 2 cases (0.5%) of endoscopic lumbar discectomy. If irrigation solution pressure becomes too high during UBE, complications including headache, neck pain, blurred vision, delirium, and drowsiness may arise as a result of increased intracranial pressure (IICP) (20). In rare cases, excessive CSF pressure can lead to retinal hemorrhage. Elevated CSF pressure can directly affect retinal veins through the optic nerve sheaths or indirectly via the surrounding subarachnoid space (19). This increase in CSF pressure can also reduce cerebral blood flow, triggering a reflexive rise in ophthalmic artery pressure, which may cause rupture of small blood vessels and venous collapse. Lee et al. highlight how elevated CSF pressure can impact ocular health (19). Although automatic pumps were not available, irrigation was standardized across all centers by suspending the saline bag 50–70 cm above the patient, which as recommended in the literature maintains epidural irrigation pressure below approximately 30 mmHg according to hydrostatic principles (4,13,15). If water outflow is insufficient, enlarging the fascia incision or creating a crosscut incision may help (15). In this study, two cases of transient vision loss occurred during the learning curve (first 100 cases), with one patient treated by laser photocoagulation and the other managed conservatively. In addition to recommendations from the literature, 10 mg of intravenous rocuronium was administered every 30 minutes to keep muscles relaxed, helping prevent fascia shrinkage and ensuring the temporary pathway through muscle remains open. No IICP symptoms (e.g., neck pain, blurred vision) were observed in cases where adequate water outflow was maintained through fascia incisions and muscle relaxants. Soliman noted that prolonged surgeries increase this risk and suggested preventing IICP by turning off irrigation and pausing for 2-3 minutes every hour (30). When signs of elevated intracranial pressure, such as increased blood pressure and decreased heart rate, appear during surgery, it is essential to ensure optimal water outflow, aspirate excess fluid, and pause briefly.

Abdominal Compartment Syndrome (ACS)

This rare complication was observed in 1 case (0.3%) during biportal endoscopic lumbar canal surgery. Although ACS is seldom reported, it has been documented in patients operated on through transforaminal monoportal or biportal endoscopic approaches (23,28). Abnormally elevated intra-abdominal pressure can lead to ACS, presenting with dyspnea and lower extremity circulation disturbances, such as cyanosis and cool extremities (17). In this case, poor triangulation led to drilling at the transverse process instead of the lamina, injuring the musculotendinous tissue between the transverse processes rather than the multifidus muscles. Upon realizing the facet joint was not lateral to the lamina, triangulation was corrected with fluoroscopy before decompression began. While water outflow was not entirely obstructed, it was inadequate. At 45 minutes into the procedure, the anesthesiologist noted increased airway pressure, reduced tidal volume, and hypotension. When the drapes were removed post-surgery, the lower extremities appeared cyanotic and cool, and the abdomen was distended. The patient was then repositioned supine, and abdominal distension was confirmed. General surgery consultation was obtained, and an abdominal ultrasound revealed fluid collection; laparoscopic exploration was performed, evacuating approximately 4 liters of irrigation solution from the abdomen (Figure 4). No retroperitoneal organ damage was identified. Upon reduction of intra-abdominal pressure, the patient's extremity circulation and dyspnea markedly improved. After one day of ICU monitoring, with no major issues detected, the patient was discharged on postoperative day three. The main signs of ACS include oliguria or anuria, reduced cardiac output, decreased renal perfusion, and impaired lower extremity circulation due to high airway pressure (3,22). Dyspnea may be an early clinical indication (8). Delayed ACS diagnosis and treatment can significantly raise morbidity and mortality risks, potentially leading to multiorgan failure or death (23,24). To

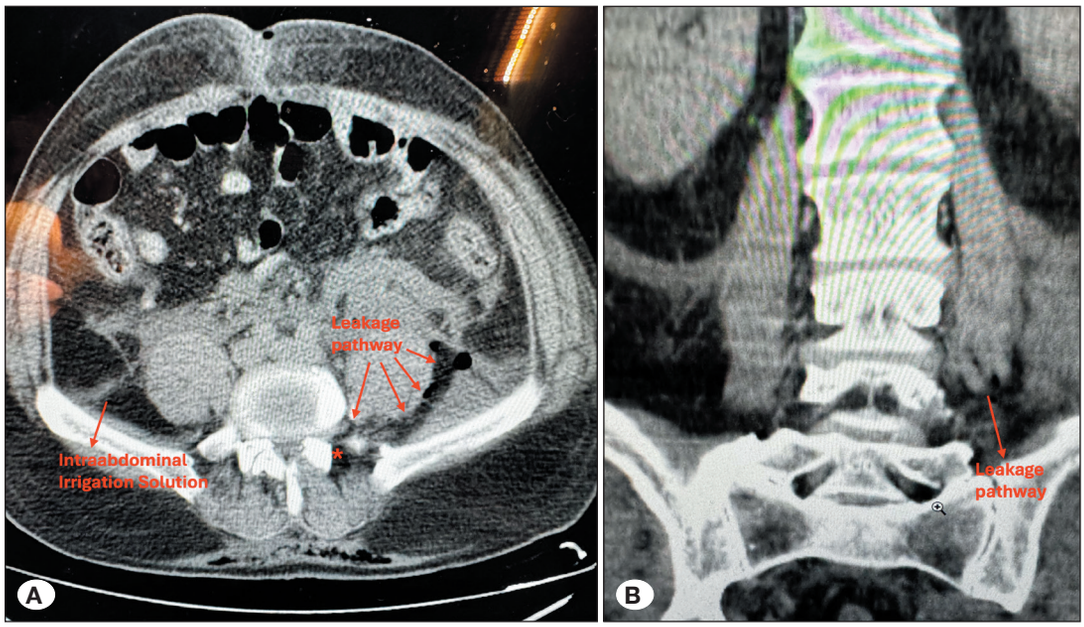

Figure 4: A) Axial computed tomography (CT) scan of abdominal compartment syndrome. The figure confirms the escape route of the solution into the retroperitoneal space due to drilling of the left L4 transverse process, as seen on abdominal CT after the procedure. **B)** Coronal CT reconstruction of the same patient. Asterix demonstrates inadvertent drilling of the transverse process **(A)**.

prevent such complications, surgeons should confirm triangulation with lateral and anteroposterior radiographs if orientation is uncertain. Additionally, measuring outflow fluid can alert the surgeon to any discrepancy between input and output, indicating possible intra-abdominal fluid leakage.

The primary limitation of our study is the relatively short follow-up period, which may limit the assessment of long-term outcomes. Nonetheless, the study's strength lies in its large patient population, making it one of the highest-volume studies in the literature for this technique. This extensive dataset offers valuable insights into early postoperative outcomes and procedural safety.

Another important limitation of this study is the lack of automated pressure-controlled irrigation systems across all three centers. The absence of precise manometric monitoring may still represent a methodological weakness and could have contributed to pressure-related complications. Future studies incorporating continuous pressure measurement are warranted.

CONCLUSION

In UBE, common complications seen in microsurgery, such as dural tears, root injuries, and epidural hematomas, are also encountered. However, unique complications associated with irrigation solutions, including abdominal compartment syndrome, retinal hemorrhage, and increased intracranial pressure, have also been observed. As surgical experience grows and these experiences are documented with preventive measures shared, complication rates are expected to decrease, making the method safer. Ensuring optimal water outflow, achieving precise triangulation and orientation, and controlling epidural bleeding to maintain a clear view are techniques that can significantly prevent most potential complications.

Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: MIO, OKD
Data collection: GU, MCE
Analysis and interpretation of results: MIO, IS
Draft manuscript preparation: MIO, OKD
Critical revision of the article: MIO, IS, GU, MCE, OKD
Other (study supervision, fundings, materials, etc...): MIO, OKD
All authors (MIO, OKD, GU, MCE, IS) reviewed the results and approved the final version of the manuscript.

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