The study of the clinical results of minimally invasive spine surgical techniques: the presentation of new surgical approaches

Thesis of doctoral (Ph.D.) dissertation

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I. Introduction

Degenerative spinal problems associated with pain and motion restriction can be treated with spinal surgical procedures when conservative therapeutic options are not effective. As part of the new trends in spinal surgery, minimally invasive spine surgical (MISS) solutions have entered our everyday practice. In contrast to the practices of previous decades, the MISS method considers the preservation and sparing of soft tissues as an essential aspect. Thus, the surgical time and surgical and anaesthetic risks can be reduced by omitting surgeries with large open wounds accompanied by detached back muscles of the spine. Due to the minor postoperative pain, patients can often be mobilized the day after surgery. With faster recovery, lower pain levels and fewer complications (such as wound infections, thrombosis, pneumonia or decubitus), the hospital stay can be reduced, and the patient can go home sooner. MISS methods represent the main direction in the toolkit of our clinical workgroup.

II. Objectives

This paper examines technical solutions for treating various causes of abnormalities in the dorsal and lumbar spine. Each solution represents a MISS approach to replacing a previous, less tissue-sparing spinal surgical technique.

1. The extrapleural anterolateral spinal approaches examined in the first chapter provide a tissue-sparing solution for the treatment of the difficult-to-reach anterior column of the dorsal spine. Similar to traditional methods that open the pleura, they provide direct visibility of the anterior-lateral part of the spine, enabling the necessary decompression. At the same time, by creating the working channel on the outer side of the parietal pleura, no iatrogenic pneumothorax develops, thus eliminating the need for chest tube insertion after surgery, hence avoiding an average of 3 days of intensive care treatment. Patients can be mobilized the day after surgery, and accordingly, patients can be discharged several days earlier compared to thoracotomy explorations.

2. In the second chapter, the combination of ligamentotaxis and MISS provides a solution for acute traumatic thoracolumbar spine injuries of type A and C compression origin, according to the AO classification (AO foundation [Arbeitsgemeinschaft für Osteosynthesefragen]). The method allows the indirect nerve decompression resulting from trauma, its decompression, and the indirect correction of traumatic deformity without injury. During the study, the effectiveness of ligamentotaxis was confirmed by measurements.

3. In the third chapter, we examine the surgical solutions of the oblique lumbar interbody fusion technique (OLIF) and the anterior lumbar interbody fusion technique (ALIF), which were first started in Hungary at our clinic in the treatment of degenerative diseases of the lumbar spine. Suppose the ALIF technique in the lumbosacral transition is contraindicated due to the low bifurcation of the great vessels. Can the lumbosacral OLIF technique performed from the right provide a suitable alternative?

4. In the fourth chapter, we examine a zygoapophyseal joint implant under development for use in the lumbar spine, which offers an alternative to transpedicular screwing. Our question is, can the small joint implant provide long-term stability similar to transpedicular screw fixation? If the small joint implant dislocates, can it cause direct side effects, such as nerve compression and loss of stability?

III. Extrapleural anterolateral approach

III.1. Introduction

In thoracic spine surgery, operating on pathologies that require ventral decompression of the spinal cord can be challenging. The majority of anterolateral approaches to the dorsal spine are characterized by the fact that, since the pleural cavity is opened, in most cases, a few days of intensive care unit stay and continuous suction through a chest tube are essential for the absorption of iatrogenic pneumothorax after surgery. Extrapleural approaches were developed to prevent the development of iatrogenic pneumothorax, during which the parietal pleura is carefully separated from the inner surface of the chest wall to reach the anterolateral surface of the spine without perforation of the pleura and consequent pneumothorax. In Hungary, minimally invasive anterolateral extrapleural spine approaches were first used at our clinic.

III.2. Options of the thoracal appraoches

Minimally insvasive anterolateral extrapleural approach

In this chapter, we would like to illustrate the minimally invasive extrapleural spinal approach with the following three cases. Thanks to the extracavitary approach, we did not experience pneumothorax after the operations in any of the cases.

Removal of a calcified disc herniation from the thoracolumbar junction

The middle-aged obese female patient had been suffering from low back pain for decades. In the months before the surgery, her walking distance decreased to 5-10 meters, and she experienced diffuse pain radiating to the waist, hips and lower extremities upon exertion. During her physical examination, we found no objective neurological abnormalities except bilateral Achilles areflexia. The performed CT and MRI examination of the thoracic and lumbar spine showed a ruptured, partially calcified disc herniation located in the Th. XII - L. I. segment, almost filling the spinal canal, which

compressed the conus-cauda transition (Fig 3.1). Given the almost inability to walk and the significant space-occupying Th. XII. disc herniation, we recommended its surgical treatment.

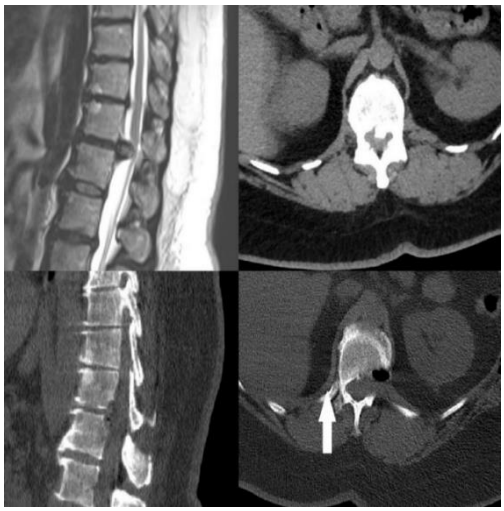


Fig 3.1. *The upper row shows the preoperative MRI and CT images of the Th. XII. calcified disc herniation compressing the spinal cord, and the lower row shows the condition after its removal. The axial image (lower row) shows the kidney on the left side in the retroperitoneum next to the Th. XII. The vertebra, the diaphragm, the lung tissue, and the pleural duplication extending next to the spine are depicted as a thin strip next to the rib (white arrow).*

III.4.5. Thoracic disc herniation removal with direct anterior decompression

The male patient, born in 1990, was diagnosed with sero-positive Devic disease in 2013. The patient developed significant visual impairment and severe paraparesis, with spastic lower limb tonus. In May 2017, the patient presented with a new complaint: his trunk muscles weakened, mild trunk ataxia developed, and his paraparesis significantly worsened. An MRI of the dorsal spine was performed, which showed a herniated disc in Th. VI (Fig 3.2). According to the neurologist's opinion, the etiological role of the herniated disc in the patient's worsening condition could not be ruled out. Thus, in agreement with the patient, we decided to remove the herniated disc to preserve and, if possible, improve the patient's ability to walk.

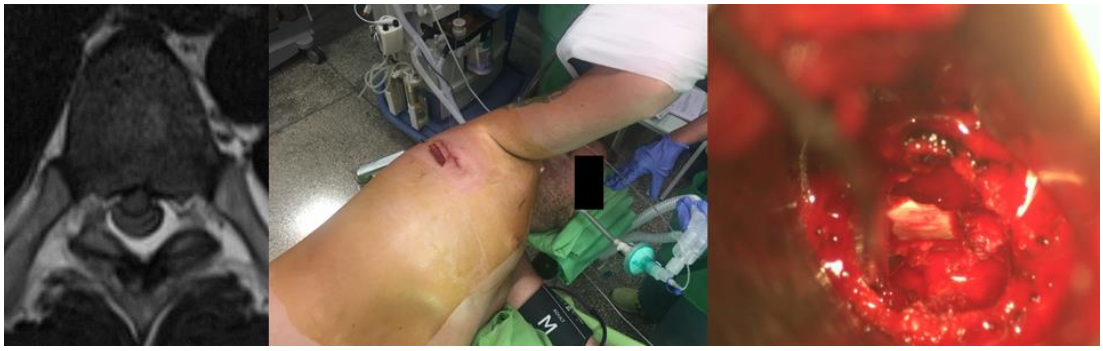


Fig 3.2.*The left image shows the Th. VI. herniated disc. The middle picture shows the closed surgical wound and the rib piece that was removed for surgical exposure after the operation. The patient's right arm was tied up and padded so that the part below the axillary groove was accessible. The far right image shows the anterior surface of the dura mater under a microscope after the herniated disc was removed.*

III.4.6. Thoracic corpectomy with direct anterior decompression for spondylodiscitis

In May 2017, a 64-year-old male patient was diagnosed with bilateral pneumonia and then underwent chest drainage in several stages due to a large amount of pleural exudate. A spine CT and MRI examinations were performed due to back pain and severe paraparesis. The scans confirmed spondylodiscitis of the Th. X-XI. vertebrae and consequent myelon compression, with local kyphosis. Given the severe paraparesis, we decided on surgical treatment (Fig 3.3).

Fig 3.3. *The images show the projection of the Th. X. and Th. XI. vertebrae affected by spondylodiscitis onto the chest wall. The line running obliquely forward and downward shows the planned skin incision. The left side of the lower pair of images shows an intraoperative image of the approach. A Synex cage is visible at the site of the Th. X. and Th. XI. corpectomy.*

III.5. Discussion

Nowadays, in our country, costotransversectomy and transthoracic thoracotomy are standard practices in thoracic spine surgery. In addition to these methods, an extrapleural, minimally invasive lateral spine approach is a real alternative. During the approach used in our case, the skin incision is 6 cm, the patient lies on his side, and according to the course of the rib, we can achieve the same result from a straight incision as from larger, curved incisions. Keeping the minimally invasive approach in mind, we strive to traumatize the muscle and skin unit as little as possible. In addition to the much smaller incision, we minimize tissue destruction by blunt preparation wherever possible, thus significantly reducing the chance of post-thoracotomy pain syndrome. If the disease process and the surgical response to it require spinal fixation, we also perform it using a minimally invasive method. Compared to the transthoracic approach, the retropleural approach takes an average of 30 minutes longer due to careful separation of the parietal pleura. The extrapleural approach results in faster recovery, lower pain, and fewer complications.

III.6. Conclusion

The minimally invasive lateral extrapleural spine exposure (miLECA) involves a smaller exposure (6 cm incision) and is more soft tissue-friendly in reaching the target area. Since the parietal pleura is bluntly separated from the chest wall, we remain “behind” the parietal pleura throughout, which makes chest tube placement unnecessary. While previously, our patients were observed in the intensive care unit with a chest tube for an average of three days by general Hungarian practice, this has become unnecessary: emission occurs on the average on the fourth postoperative day. Overall, the complication rate is lower. These factors mean faster recovery, shorter hospital stays, and a lower burden for both the patient and the healthcare system.

IV. Percutaneous spine fusion combined with whole-body traction in the acute surgical treatment of AO A and C type fractures

IV.1. Introduction

In the last few decades, in the treatment of TLICS 5-10 thoracolumbar fractures, surgical repair techniques came to the fore because of early surgical care, while conservative methods applied to the treatment of elderly or multimorbid patients. Az instabil gerinctörések sebészeti kezelésében három terápiás célt szükséges teljesíteni: az idegi struktúrák dekompressziója, a traumás deformitás korrekciója és a gerinc stabilitásának helyreállítása a dekompresszió és deformitás korrekció megőrzése mellett. There are three main surgical therapeutic goals associated with unstable spine fractures: the decompression of the nerve structures, the correction of the traumatic deformity, and restoring stability to the spine while preserving the fracture reduction.

Regarding surgical techniques, the above-mentioned therapeutic goals can be completed in an open-direct or covered-indirect manner, depending on the type and severity of the fracture and neurological state. Our goal is to draw attention to an acute, indirect decompression method that involves the combination of whole-body traction and percutaneous pedicle screw fixation. The presented method can be used in AO A or C types compression thoracolumbar injuries.

IV.2. The surgical technique

As mentioned earlier, three main therapeutical goals are associated with unstable spine fractures: the decompression of the nerve structures and the correction of the traumatic deformity are achieved by whole-body traction. The third goal, restoring stability to the

thoracolumbar spine while preserving the fracture reduction, is achieved by percutaneous pedicle screw fixation.

Indirect decompression with whole-body traction

The ligamentotaxis is achieved by whole-body traction along the longitudinal axis of the spine by pulling the patient's shoulders and ankles or pelvis. This procedure is carried out with a gradually increasing force manually for 20-30 seconds during the whole-body traction. Lateral fluoroscopy control is implemented during and following the whole-body traction to control the tractive force. The theoretical possibility of 'overstretching' is prevented by fracture selection (i.e. only compression injuries) and X-ray control during whole-body traction. Often maximum human strength was necessary. Often maximum human strength was necessary. If and when required, the maneuver can be repeated several times. Typically, substantial improvements can be noticed on C-arm images regarding the vertebral body's height, traumatic kyphosis, and traumatic spinal stenosis. Time does not seem to have a substantial effect on whole-body traction in the operating room in relaxed patients under general anesthesia, but the movement of the patient does. For this reason, whole-body traction was immediately followed by MISS of the spine. Only immediate post-traction spinal fixation can ensure that the effect of whole-body traction is not reduced.

IV.3. Methods

Fifteen patients meeting the following eligibility criteria were operated sequentially with the combination of whole-body traction and percutaneous minimally invasive spine fixation. Thoracolumbar injuries AO A type and AO C type without distraction origin were included. Data were analyzed retrospectively.

The following measurements were made on the preoperative and postoperative CT scans. The traumatic kyphosis was measured as the angle between the upper adjacent vertebral body's upper endplate and the lower adjacent vertebral body's lower endplate.

The vertebral height was measured as the distance between the ventral-caudal corner of the upper adjacent vertebral body and the ventral-cranial corner of the lower adjacent vertebral body. The same measurements were performed on the dorsal side of the vertebral body. The AP diameter of the spinal canal was measured at the narrowest level in the mediansaggital plane on preoperative CT scans. The same points were measured on the postoperative CT scans. The operative time and blood loss were recorded. Besides the extremity neurological function, the bladder and bowel function were assessed. No additional instrumented ligamentotaxis was necessary in the cases. No neuromonitoring was applied since it is not possible in acute cases in our department.

IV.4. Results

The presented whole-body traction combined with percutaneous spine fusion was performed in fifteen spine trauma patients (six female, nine male) injured from compression forces. The average age of the patients was 47 years old (range 20-74). Vertebral fractures developed in the following distribution. Th.XII: 5, L.I: 7, L.II: 1, L.III: 1, L.IV: 1. A total of 139 screws were implanted into 70 segments. In the case of three older

patients, the screw implantation was combined with vertebroplasty augmentation. In two cases, we performed one level laminectomy also.

Clinical follow-ups averaged 16 months. One patient underwent surgery 4 months before the article submission. One of our patients has been lost for the twelve-month follow up.

The spinal canal space narrowing showed an average 6.5 mm (range 2.6 mm-14.3 mm) postoperative improvement. The fractured vertebrae's height gain was an average of 11.0 mm (range 3.9 mm-21.9 mm) ventrally and an average of 5.4 mm (range 1 mm-11.2 mm) dorsally after the surgeries. Preoperative traumatic kyphosis was experienced in 14 cases with an average preoperative kyphosis of 17 degrees and an average postoperative kyphosis of 1.8 degrees. In the only L.IV fracture, preoperative kyphosis of -21.3 degrees and postoperative kyphosis of -15.3 degrees were measured. Operative time averaged 2 hours and 34 minutes (range 70-325 minutes), and blood loss averaged 250 ml (range 150-400 ml). The average hospital stay was six days (range 4-9 days). No neurological complications were observed, and we didn't experience wound healing problems. Eleven patients were neurologically intact or had a slight neurologic disorder (Table 3), such as temporary numbness (Fig. 4.1).

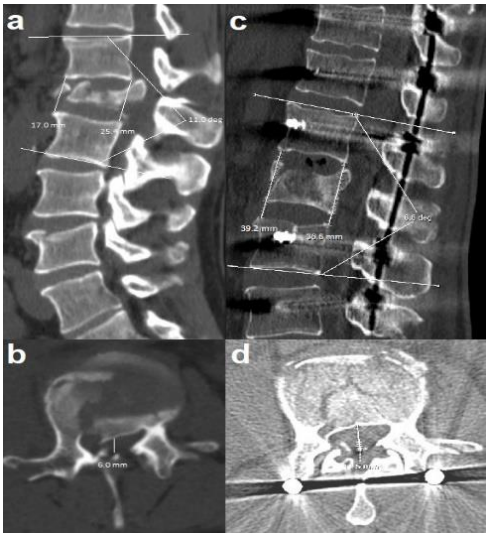


Fig. 4.1 *An AO C type L.I. injury can be observed on the left sagittal (a) and axial (b) images. The rotation of the fractured spine (C-type injury) is well represented by the malalignment of spinosus processes in the preoperative images. The increase in sagittal diameter of the spinal canal and the realignment of spinosus processes are obvious on the postoperative sagittal (c) and axial (d) images on the right side. The patient is neurologically intact.*

Among the fiftteen cases, the ligamentotaxis showed slight effectiveness in restoring spinal canal narrowing in two cases, although traumatic kyphosis and height reduction were corrected in these cases. One of them was a twenty-year-old male patient struck by a heavy log and suffered an AO C type L.IV. fracture. However, despite the frightening CT scans, the young patient was miraculously neurologically intact, so laminectomy was omitted. The only complaint was slight numbness in the L.4 dermatome left side, which disappeared to the three months follow-up.

The other case was a 64 years old male who was hit by a car. The patient suffered an unstable Th.XII. vertebral body fracture (C type by AO classification), associated with serious spinal canal stenosis. The complete transverse lesion with paraplegia developed at the moment of the accident. In our opinion, the benefit of decompression in complete neurological deficit (acute paraplegia, Frankel A) resulting from severe spine fracture dislocation is questionable.

At an 18-month follow-up, CT and MRI scan were performed. The latter still not depicted the development of syrinx, the patient's neurological state was unchanged. The patient's follow-up continues.

IV.5. Discussion

The combination of whole-body traction and MISS can be applied safely and effectively for acute treatment of spinal trauma resulting from compression forces throughout the spine, including the sacral region, nevertheless, the number of relevant publications is limited. The indirect decompression provided by the extracorporal ligamentotaxis not only increases the height of the fractured vertebral body and the neuroforamen, however, the correction of the traumatic kyphosis and spinal canal stenosis is also discernible.

The whole-body traction is not recommended in specific cases: the mechanism of injury or the radiological signs suggests ligamentous injury. So, it is clearly contraindicated in distraction type injuries (type B by AO classification). In clear compression injuries (type A) by AO classification, the method is well suited. It is also well applicable for type C injuries, however, the type C injuries with distraction origin by AO classification requires caution.

The presented method is recommended in patients without neurological signs or with slight neurologic impairment. In patients showing more severe neurological deficits, the

application of the method is a matter of individual consideration unless a rupture of the spinal cord is evident. In cases of severe neurologic impairment, a supplementary laminectomy at the level of the traumatic stenosis can be beneficial.

IV.6. Conclusion

In most cases, the combination of extracorporal ligamentotaxis and minimally invasive spine surgery proves to be an effective, simple, rapid, safe and cost-effective solution regarding the surgical treatment of AO A or C type fractures resulting from compression forces obviating the use of dedicated polyaxial screws and internal traction devices. Further studies are needed to prove the results of our pilot study presenting only a small number of cases

V. Anterior and right-sided oblique lumbosacral fusions (ALIF and OLIF) with dorsal percutaneous pedicle screw fixation

V.1. Introduction

Spinal fusion treatment of degenerative spine diseases aims to decompress nerve structures, reduce deformities, and restore stability.

There are two main decompression techniques in lumbosacral fusion surgery. The dorsal approaches (e.g. PLIF, TLIF) grant the direct decompression of nerve structures. In contrast, the anterior and oblique group (e.g. ALIF, OLIF, XLIF) allows indirect decompression (Fig. 5.1).

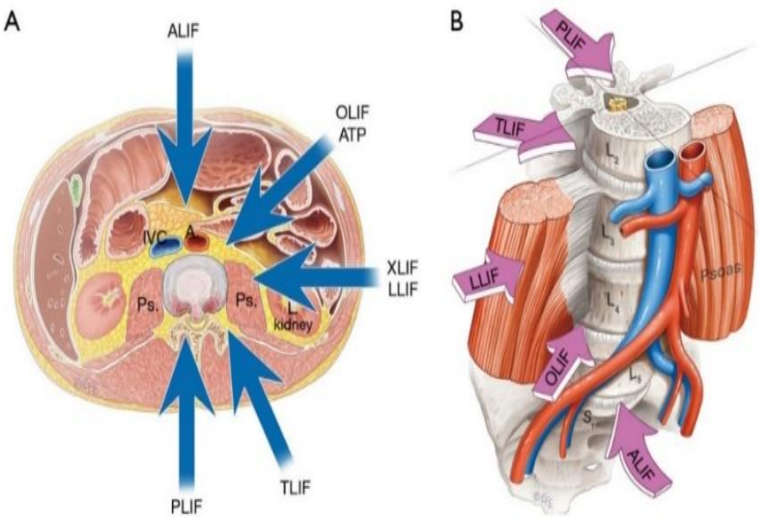


Fig 5.1. *The approaches of the lumbar fusion techniques (Mobbs RJ, Phan K, Daly D, Rao PJ, Lennox A. Approach-Related Complications of Anterior Lumbar Interbody Fusion: Results of a Combined Spine and Vascular Surgical Team. Global Spine J. 2016;6(2):147-154. doi:10.1055/s-0035-1557141)*

Due to vascular anatomical characteristics, operating on the lumbosacral junction could be challenging from the anterior or oblique direction. The lumbosacral disc can be approached between the common iliac artery and vein (CIA and CIV) or lateral to them. At least four techniques exist in the anterior and oblique fusion technique group to complete the abovementioned surgical goals for the lumbosacral junction.

The best-known is the classic ALIF technique, when the patient is in Da Vinci position, and the approach is from the anterior direction via Pfannenstiel incision, reaching the disc between the blood vessels.

The second option regarding cage insertion is also a "between the blood vessels" technique. However, the lateral decubitus position and the incision place suggest that this combines the ALIF and OLIF techniques.

Further surgical options would be the lumbosacral extension of the OLIF technique lateral to the blood vessels from the right or left side. The lateral lumbar interbody fusion (LLIF), also known as extreme lateral interbody fusion (XLIF) or direct lateral interbody fusion (DLIF) method, is unsuitable for the lumbosacral junction.

The main risk of anterior and oblique approaches to the spine is bleeding. The more obscured the lumbosacral disc is by the common iliac veins and arteries, the more the blood vessel must be mobilised and retracted to remove the degenerated disc and insert the cage, increasing the risk of bleeding and thrombosis.

Magnetic resonance imaging (MRI) can predict the possibilities of blood vessel mobilisation. The classic ALIF method can be recommended if the bifurcations of the common iliac arteries and veins (CIA and CIV) are located cranially from the fifth lumbar disc, and the anterior surface of the fifth lumbar disc is free or only minimal CIV mobilisation is required. If the bifurcations are located low, or the left CIV does not have a fat plane or is attached to osteophytes, the mobilisation of CIV is associated with a greater risk of bleeding (Fig 5.2).

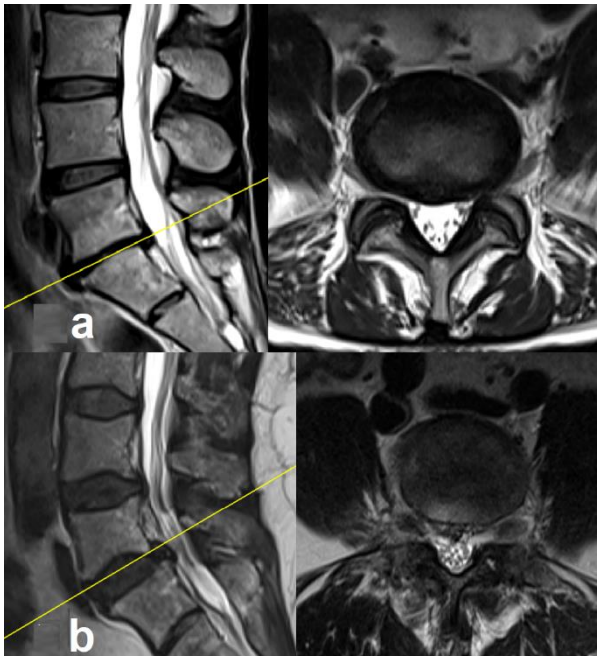


Fig 5.2. *The vascular anatomical variations determine the choice between the anterior or oblique approach to the lumbosacral segment. The (a) picture represents an optimal patient for ALIF surgery. The common iliac vessels do not cover the fifth lumbar disc. Minimal or no vessel mobilisation is necessary to implant the ALIF cage. In the (b) picture, the bifurcation is low and attached to an osteophyte; therefore, mobilising the left common iliac vein is risky. In the latter case, handling the segmental veins of the right common iliac vein is less demanding during a right-sided OLIF+D surgery.*

Among the oblique approaches to the lumbosacral junction, the left-sided "lateral to blood vessels" OLIF technique is usually preferred. In the absence of literature data, anecdotally, the right-sided "lateral to blood vessels" lumbosacral OLIF technique is considered dangerous and the least preferred technique.

This single-centre study aimed to demonstrate the feasibility and safety of the right-sided (left lateral decubitus position) lumbosacral OLIF approach compared with the classic ALIF technique based on clinical and radiological measures.

V.3. Methods

V.3.1. Patient population

This study included only patients who received one-segment lumbosacral surgery with supplementary dorsal percutaneous pedicle screw fixation.

From February 2018 to February 2020, 21 patients underwent classic ALIF surgery (Johnson and Johnson, DePuy Synthes, Synfix evolution cage) in the lumbosacral segment supplemented with dorsal percutaneous pedicle screw fixation (ALIF+D).

Furthermore, between 2016 and 2022, 20 patients were operated on with the right-sided lumbosacral OLIF approach receiving supplementary dorsal percutaneous pedicle screw fixation (OLIF+D).

At the time of surgery, the ALIF+D patients were 47.2±10.3 (range: 18-63) years old, while the OLIF+D patients were 54.2±10.5 (37-77) years old.

The clinical follow-up time was 21.4±21.2 (range: 7–84) months for the OLIF+D patients and 18.4±8.9 (range: 8-40) months for the ALIF+D patients. Table 1 presents the demographic characteristics of both patient groups.

V.3.2. Outcome assessment

Patient-reported outcomes included the visual analogue scale (VAS) for low-back and leg pain and the Oswestry Disability Index (ODI) collected before the surgery and during the follow-up.

In addition, radiological measurements were made on the preoperative and follow-up CT scans obtained in the same CT scanner at Pécs Diagnostic Center.

Segmental lordosis was measured in the median sagittal plane as the angle between the fifth lumbar vertebral body's upper endplate (L5) and the sacral plateau (S1). The anterior segmental height (ASH) was measured in the median sagittal plane as the distance between the fifth lumbar vertebral body's ventral cranial corner and the ventral corner of the sacral plateau. For the posterior segmental height (PSH), similar measurements were performed at the posterior margins.

The fusion was assessed on CT with bone window. The definition of fusion is controversial, and there is no widely accepted consensus on the measurement technique of spinal fusion. Considering the concerns about the measurement techniques, the Bridwell fusion grade was used in the present study. Postoperative flexion-extension radiographs were not performed routinely at our institution.

V.3.3. Statistical analyses

Statistical analyses were performed using SPSS, version 29.0 (IBM Corp., Armonk, NY, USA).

As part of our variables were measured on ordinal scale and non-normality was indicated by significant Shapiro-Wilk test ($p \leq 0.05$) for a number of continuous variables or the differences between their preoperative and postoperative values, nonparametric statistical tests were applied.

The Wilcoxon signed-rank test was applied to compare preoperative ASH, PSH, segmental lordosis angle, ODI, back pain, and leg pain visual analogue scale (VAS back and VAS leg) scores to postoperative ones. The Mann-Whitney U test was run to determine if there were differences in postoperative segmental lordosis angle, ASH, PSH, ODI, back and leg pain VAS scores, blood loss, or surgical time between patient groups operated by ALIF+D vs OLIF+D methods.

V.6. Results

None of the patients had severe neurological symptoms before or after surgery, and no implant failures and wound-healing problems, such as deep infection, were observed. If we compare the postoperative data of the ALIF+D and OLIF+D groups, there were no statistically significant differences between the segmental lordosis angle ($p=0.354$), ASH ($p=0.297$), PSH ($p=0.404$), ODI ($p=0.824$), or the back and leg pain VAS scores ($p=0.682$ and $p=0.979$, respectively). However, the blood loss was higher ($p=0.058$), and the surgical time was significantly longer ($p=0.009$) in the OLIF+D group compared to those operated by the ALIF+D technique. Both surgical times include the dorsal percutaneous pedicle screw fixation with repositioning to the prone position.

The only complication was experienced in our very first right-sided lumbosacral OLIF+D patient operated in 2016: the right CIV was injured, and the blood loss was 600 ml. The injury was treated with sutures without the help of a vascular surgeon.

Comparing the preoperative and postoperative data, the vertebrae's height gain ($p<0.001$) and the segmental lordosis gain ($p<0.001$) were significant in both the right-sided lumbosacral OLIF+D group and the ALIF+D group. Both techniques elicited a statistically significant decrease in the preoperative and postoperative ODI, VAS back, and VAS leg scores ($p<0.001$ for all).

Subsidence was not observed in 19 right-sided lumbosacral OLIF+D patients; only one showed Grade I subsidence with Grade III on Bridwell's fusion grade. Three patients showed Grade II fusion, and 16 resulted in Grade I fusion. In the ALIF+D group, 20 patients did not develop subsidence during the follow-up period, and only one patient showed subsidence, which was less than 25%. In this case, a Grade II fusion was formed. Two additional ALIF+D patients showed Grade II fusion, and 18 resulted in Grade I fusion.

V.7. Discussion

Pros and cons of ALIF+D and right-sided OLIF+D approaches

The ALIF and OLIF techniques offer better variability in the size and lordosis of the cage compared to the dorsal approaches. This is consistent with our paper suggesting that the ALIF+D technique resulted in a slightly higher average postoperative lordosis value than the OLIF+D technique.

Furthermore, the larger footprint due to larger cages provided by OLIF and ALIF approaches reduces the chance of cage subsidence. In this study, each group had only one subsidence with no clinical relevance. Both methods result in high bony fusion rates, consistent with our research.

In our study, the operation length of the ALIF+D was significantly shorter, which is explained by patient selection based on vascular anatomy. The bifurcation of the common iliac veins did not cover the fifth lumbar disc in the cases of ALIF+D approach. In all lumbosacral OLIF+D cases, some time-consuming vascular mobilisation was necessary. Yet handling the segmental veins of the right common iliac vein is less demanding during the right-sided OLIF+D approach than handling the bifurcation of the

common iliac veins during the ALIF+D approach, especially if the bifurcation is attached to an osteophyte. This could be advantageous if the surgeon is less experienced in the ALIF approach or has no vascular surgeon available but does not prefer the dorsal approach. The OLIF and ALIF approaches produce more favourable blood loss and surgical time results than dorsal approaches, such as TLIF. The necessity of vascular manipulation can also explain the association with more significant blood loss of the OLIF+D approach in our study.

Pros and cons of left-sided and right-sided OLIF+D approaches

The OLIF+D technique from the right side can be safely applied in the lumbosacral junction, considering the differences between the left and right sides regarding the lumbosacral blood vessel anatomy. The left common iliac artery (CIA) covers the lateral part of the left common iliac vein (CIV). The consequence is that the low-pressure CIV is wedged on the left side between the high-pressure CIA and the vertebra, so its cross-section is often flattened.

The flattened left CIV must be mobilised and retracted during the ALIF+D and left-sided lumbosacral OLIF+D surgery. The CIA covers the anterolateral half of the CIV. Due to the flattened calibre the left-sided CIV often lies on top of the junctions of the smaller incoming veins, such as the venovertebral vein or Maeng's vein, causing the entry points of the segmental iliolumbar veins and the median sacral vein are also mostly covered.

The situation is different on the right side. Before the bifurcation, the right-sided CIV is placed on the lateral side of the right-sided CIA and is less squeezed between the vertebra and the right-sided CIA, which is why its cross-section is round.

The right CIV shows a straighter course, indicating a more predictable, easier mobilisation. The critical point in mobilisation is handling the segmental veins tethering the CIV. On the right side, the iliolumbar segmental veins running to the CIV are straighter, longer and of smaller calibre, making them easier to ligate than on the left.

Therefore, the choice between the ALIF or OLIF methods depends on the given vascular situation, which requires a preoperative assessment and planning.
Our research presents experience from a single-centre with a limited number of cases. Further studies in larger cohorts of patients are needed to have more experience with the right-sided OLIF+D approach.

V.8. Conclusion

This is the first study to describe and present the early results of the right-sided OLIF+D compared with ALIF+D in the lumbosacral segment. When the ALIF+D is risky, the right-sided "lateral to vessel" lumbosacral OLIF+D technique can be an alternative, yielding similar clinical and radiological outcomes.

VI. Clinical study of the zLOCK zygoapophyseal joint implant

VI.1. Introduction

Low back pain affects nearly 100 percent of the population at least once. The underlying cause is usually degenerative instability. The goal of surgical fusion is to create the possibility of bony fusion, which also means eliminating instability. Several dorsal fusion systems are known. Most of these systems use transpedicular screws and connecting rods as standard to create fusion. Accurate screw placement is critical. Imprecise screw placement can lead to damage to the soft tissues, nerves, or blood vessels surrounding the bone. An alternative to transpedicular screws is the use of a small joint implant. It is assumed that this will help to stabilize the small joint firmly so that fusion can still be achieved.

VI.2. The zLOCK implant

We studied the possibility of minimally invasive small joint fixation using the zLOCK small joint implant developed by Zygofix. The implant is made of titanium, is inserted into the small joint space, and is attached to the small joint bone with metal hooks on both sides. During implantation, the implant takes on the curved shape of the small joint space and prevents degenerative hypermobility in the small joint. The zLOCK device is used to stabilize the motion segment of the spine. The zLOCK implant is minimally invasively inserted using a percutaneous technique or through small skin incisions (20 mm) on both sides. This reduces invasiveness, postoperative pain, surgical blood loss, and the duration of the operation and the recovery period.

Two implants were used in the study: zLOCK rev8 and its improved version, zLOCK rev9 (Fig 6.1).

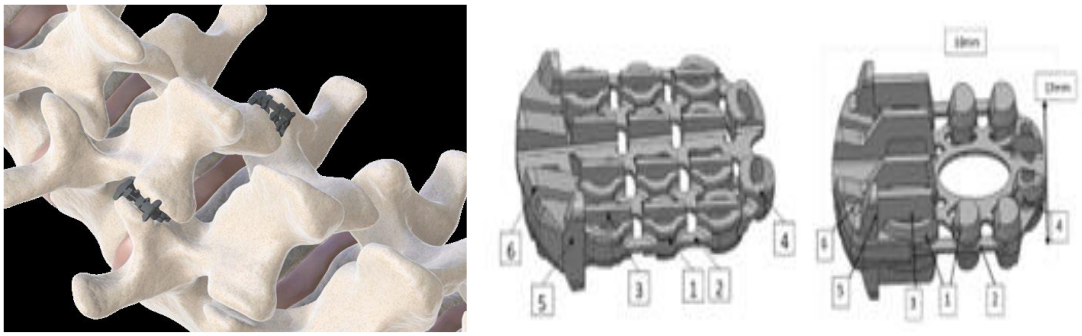


Fig 6.1. *The zLOCK rev8 implant is on the left, and the improved zLOCK rev9 implant is in the middle. On the right, the implanted small joint implant, which takes on the curved shape of the small joint, is shown.*

As a result of this pilot study, based on the experience gained from the first 12 cases, the zLOCK rev8 implant was further developed in the following way: on the improved zLOCK rev9 small joint implant, the design of the anchors that sink into the bone and provide stability was modified, their size was increased on the posterior surface of the implant (longer, wider and higher anchors). The posterior column was also made larger for the more prominent anchors. An oval hole was added to the center of the zLOCK rev9 implant, which is intended to allow for further bone bridge formation, and an optional small joint screw can also be implanted on it.

VI.3. Methods

We hypothesised that the small joint implant could replace screw rod fixation in selected cases. We conducted an open, prospective, single-arm, interventional clinical trial to verify this. The trial received approval from the Ethics Committee of the National Institute of Pharmacy and the Food and Drug Administration on February 16, 2018. The clinical trial protocol number is DNA-2275. We examined whether the new implant could be used safely and effectively during the trial. During the trial, the zLOCK

small joint implant was tested during segment stabilization, which aims to promote small joint bony fusion. It was used with OLIF surgery, with an artificial disc inserted during OLIF, and as a stand-alone in the following pathologies: degenerative spondylolisthesis Meyerding I, spinal canal stenosis, and small joint degeneration. Twenty-one patients were screened, but only 20 were included in the study and followed for 24 months. Each patient underwent six examinations, including a screening examination, a perioperative examination, and four postoperative control examinations (6 weeks, 3 months, 12 months, and 24 months after surgery). Radiological measurements were performed as detailed below, pain and disability were measured, and any surgical complications and wound healing disorders were recorded. Displacement of the small joint implant, subsidence of the artificial disc, and the development of bony fusion were also examined.

VI.3.1. Surgical techniques, implants, patient groups

zLOCK implants are placed in the lumbar facet joints on either side of the midline with or without bone grafting, using a minimally invasive, transmuscular approach. In some patients, over-the-top decompression was combined with a stand-alone zLOCK implant to achieve direct decompression (Fig 6.2).

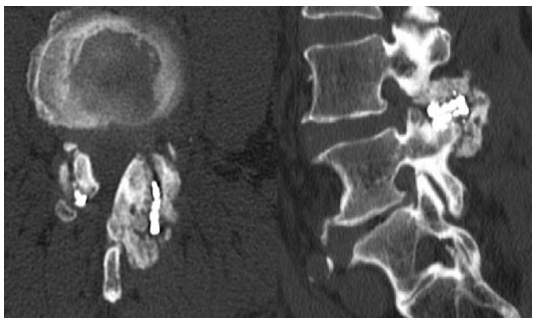
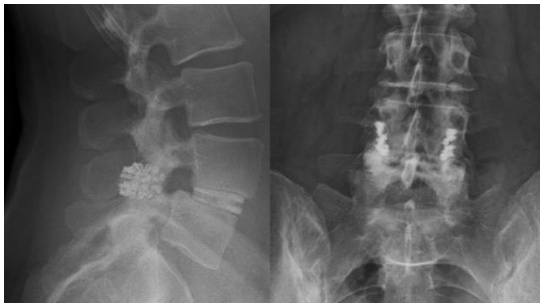


Fig 6.2. *The left shows the over-the-top decompression and bone fusion around the zLOCK. The right shows that no artificial disc was implanted, so this was a stand-alone zLOCK implant.*

Fig 6.3. *The sagittal and AP images depict the implanted OLIF cage in combination with zLOCK.*



In some patients, we achieved indirect decompression with an artificial disc implanted using the OLIF technique, in addition to stabilization with zLOCK, according to their spinal disease (Fig 6.3).

VI.3.2. Assessment of pain and disability

Preoperative and postoperative pain levels of low back and lower extremity pain were assessed using a visual analogue scale before surgery, on the day of discharge from surgery, at six weeks after surgery, and 12 and 24 months. Similarly, Oswestry disability scores (ODI) were assessed at the same time points listed above.

VI.3.3. Radiological evaluation

A 2 mm thin-slice CT scan was performed on postoperative day 1 and repeated at 12 and 24 months postoperatively to qualitatively assess the development of bony fusion by examining the bone spikes growing into the zLOCK implant.

Lateral lumbar spine flexion/extension radiographs were obtained to determine translation (the displacement between two adjacent vertebrae) and segmental lordosis (the change in the angle between two adjacent vertebrae) at 6 weeks, 3, 12, and 24 months postoperatively.

VI.3.4. Zygoapophyseal joint fusion

The literature poorly defines the radiological criteria for bony fusion following spinal stabilization surgery. In this study, we followed the FDA guidelines for the radiological definition of bony fusion of the spine:

· evidence of trabecular bone formation bridging the vertebrae that make up the affected segment (e.g., between the affected vertebral endplates, in or around intervertebral disc replacement devices, in or around the small joints); translational motion <3mm; and angular motion <5°.

VI.4. Results

The 20 patients underwent surgery at the Department of Neurosurgery, University of Pécs, between 2018 and 2022. The average surgical time from skin incision to skin closure was 213 ± 42 minutes (135-275 minutes).

VI.4.1. Adverse events (AE) and serious adverse events (SAE)

In the case of zLOCK rev8, we observed 2 SAEs: one case of wound infection and one patient requiring further surgery because the cage had sunk into the underlying vertebral body due to subclinical osteoporosis. Therefore, in this case, additional spinal stabilization was performed with cement-augmented transpedicular screws. We observed a single AE with the zLOCK rev8: asymptomatic zLOCK rev8 migration from the facet joint (Fig 6.4).

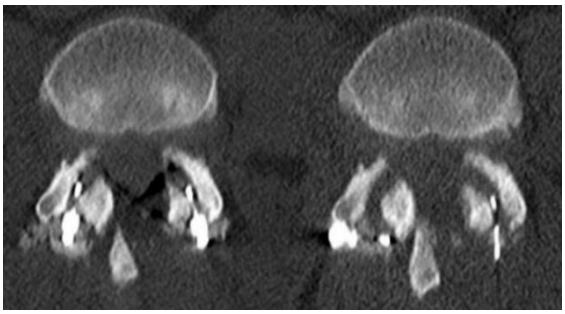


Fig 6.4. *The upper image shows a control CT scan taken on day 1 after surgery. The lower picture was taken 1 year after surgery: it shows the migration of the zLOCK rev8 on the left. The patient was asymptomatic.*

In the case of zLOCK rev9, we observed 3 SAEs: 3 patients required further surgery due to instability-related pain due to zLOCK rev9 dislocation. In these cases, additional stabilization of the spine was performed using transpedicular screws with an OLIF cage. As a result, their complaints improved significantly. No complications were causing neurological or other permanent damage. We observed two AEs in the case of zLOCK rev9: asymptomatic zLOCK rev9 dislocation from the small joint in two cases. Figure 6.5 shows an example of a zLOCK rev9 dislocation.

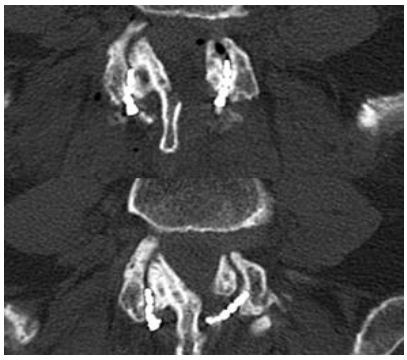


Fig 6.5. *The zLOCK rev9 was slipped out on the right side. The left CT image was taken 1 day after surgery; the right CT image was taken 12 months after surgery. The patient was asymptomatic.*

In all patient groups, significant improvements were observed in VAS and ODI during the study's follow-up period. Due to the small number of patients, it is impossible to draw statistical conclusions. Both quantitative (translational and angular deviation measurements) and qualitative (bony spike identification on thin-slice CT images) radiological examinations showed small joint bony fusion at 24 months in all patients in groups A, C, and D. However, in group B, bony fusion did not develop in patient 19 at 24 months. It should be noted that bony fusion was not yet present in patients 6, 7, and 8 in group A at 12 months after surgery.

VI.5. Discussion

Ergonomic systems like the zLOCK system are implanted into the zygoapophyseal joint space. During implantation, they adapt to the unique shape of the small joint space and prevent degenerative hypermobility in the small joint. Our clinical study has shown that the zLOCK zygoapophyseal joint implant can be an alternative to transpedicular screw-

rod systems in selected cases. It can be inserted percutaneously with minimal blood loss. Based on the experience gained from the first 12 cases of the study, and especially on the degree of segmental stabilization assessed in patients 02-13, further implant development happened.

VI.6. Conclusion

Our current clinical study was conducted as a pilot study to evaluate the safety of the zLOCK facet fusion system. As a result, we concluded that zLOCK can stabilize the lumbar segment and achieve bony fusion of the facet joint 24 months after surgery if the implant remains in the facet joint. It should be noted that radiological detection of fusion is challenging due to the metal artifact that develops around the zLOCK implant. The success rate of zLOCK in achieving fusion appears to be better when combined with an OLIF cage. The zLOCK, even when displaced, never caused neurological damage; the implant migration was always dorsal. zLOCK rev9 was associated with more dislocations than zLOCK rev8. Therefore, further modifications are needed to both the zLOCK facet joint implant and the surgical technique and instruments to ensure the zLOCK remains within the facet joint. Although the small number of patients makes it impossible to conclude the effect of zLOCK on VAS and ODI, the improvement appears to be similar to the results of studies with decompression only, without implant placement. Further studies are needed to demonstrate the efficacy of fusion, especially zLOCK small joint fusion, on VAS and ODI in lumbar degenerative spine diseases.

Publication list **(overall impact factor 15.2)**

Publications serving as the basis for this thesis

1. Szabó V, Nagy M, Büki A, Schwarcz A. Percutaneous Spine Fusion Combined with Whole-Body Traction in the Acute Surgical Treatment of AO A- and C-Type Fractures: A Technical Note. World Neurosurg. 2022 Mar;159:13-26. doi: 10.1016/j.wneu.2021.12.032. Epub 2021 Dec 13. PMID: 34915207. Impact factor: 2.2

2. Szabó V, Berta B, Nagy M, Kulcsár D, Perlaki G, Schwarcz A. The Alternative Approach to the Lumbosacral Segment: The Right-Sided Oblique Lumbar Interbody Fusion Compared with Anterior Lumbar Interbody Fusion. World Neurosurg. Published online February 22, 2025. doi:10.1016/j.wneu.2025.123823 Impact factor: 2.0

3. Szabó, V., Lakosi, F., Nagy, M., Dóczi, T., Büki, A., & Schwarcz, A. (2022). Minimálisan invazív és O-arm asszisztált en bloc gerincdaganat-reszekciók [Minimally invasive and O-arm assisted en bloc spinal tumor resections]. Ideggyogyaszati szemle, 75(1-02), 65–72. https://doi.org/10.18071/isz.75.0065 Impact factor: 0.9

4. Szabó, V., , Büki, A., , Dóczi, T., , & Schwarcz, A., (2018). Minimálisan invazív, extrapleuralis, anterolateralis gerincfeltárás [Minimally invasive, extrapleural-anterolateral approach to the spine]. Ideggyogyaszati szemle, 71(9-10), 293–301. https://doi.org/10.18071/isz.71.0293 Impact factor: 0.9

5. Minimálisan invazív, anterolateralis, extrapleuralis gerinc feltárás: esetismertetések

Gerincgyógyászati szemle (ISSN: 2064-8324) 4: (2) pp. 34-41. (2017)

Further publications

6. Hocsak, E., Szabo, V., Kalman, N., Antus, C., Cseh, A., Sumegi, K., Eros, K., Hegedus, Z., Gallyas, F., Jr, Sumegi, B., & Racz, B. (2017). PARP inhibition protects mitochondria and reduces ROS production via PARP-1-ATF4-MKP-1-MAPK retrograde pathway. Free radical biology & medicine, 108, 770–784. https://doi.org/10.1016/j.freeradbiomed.2017.04.018 Impact factor: 6

7. Környei, B. S., Szabó, V., Perlaki, G., Balogh, B., Szabó Steigerwald, D. K., Nagy, S. A., Tóth, L., Büki, A., Dóczi, T., Bogner, P., Schwarcz, A., & Tóth, A. (2021). Cerebral Microbleeds May Be Less Detectable by Susceptibility Weighted Imaging MRI From 24 to 72 Hours After Traumatic Brain Injury. Frontiers in neuroscience, 15, 711074. Impact factor: 3.2

Lectures

12. MAY. 2018. A Magyar Idegsebészeti Társaság és a Magyar Neuroonkológiai Társaság Közös Kongresszusa, Pécs: Extrapleurális feltárás alkalmazása a gerinc degeneratív, traumás és gyulladásos kórfolyamatiban

Poster presentations:

4-6. OKT, 2012: A Magyar Biokémiai Egyesület Jelátviteli Szakosztályának III. Konferenciája, Esztergom: A PARP-1 extranukleáris hatásainak vizsgálata

Rácz Boglárka, Szabó Viktor, Hocsák Enikő, Kálmán nikoletta, Gallyas Ferenc, Sümegi Balázs

13-16. JUN, 2012: FEBS 3+Meeting, Opatija, Croatia: A new mechanism for cytoplasmatic effect of PARP-1 Boglarka Racz, Viktor Szabo, Eniko Hocsak, Ferenc Gallyas JR, Balazs Sumegi

03. SEP, 2011: 4th European Conference on chemistry for Life Sciences (4ECCLS): A new mechanism for cytoplasmatic effect of PARP inhibitor PJ-34

Boglarka Racz, Viktor Szabo, Eniko Hocsak, Ferenc Gallyas JR, Balazs Sumegi

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Percutaneous Spine Fusion Combined with Whole-Body Traction in the Acute Surgical Treatment of AO A- and C-Type Fractures: A Technical Note

Viktor Szabó, Máté Nagy, András Büki, Attila Schwarcz

BACKGROUND: **A diminished level of pain following the operation and shortened hospitalization are the distinct advantages of minimally invasive spine surgery (MISS). However, manipulating the spine with additional MISS tools (e.g., distraction and compression devices) is often cumbersome. Our paper draws attention to a cost-free, fast, indirect decompression method that can be used in the acute treatment of thoracolumbar spine fractures. The presented method involves ligamentotaxis by whole-body traction in the operating room combined with percutaneous spine fixation.**

METHODS: **Fifteen patients with thoracolumbar injuries A type and C type (without distraction) by AO classification were operated sequentially with the combination of whole-body traction and percutaneous minimally invasive spine fixation. Data were analyzed retrospectively.**

RESULTS: **A total of 139 screws were implanted into 70 segments in 6 female and 9 male patients. The average clinical follow-up was 16 months. Average preoperative traumatic kyphosis was 17 degrees, and an average postoperative kyphosis was 1.8 degrees. The fractured vertebrae's height gain was an average of 11.0 mm (range 3.9–21.9 mm) ventrally and an average of 5.4 mm (range 1–11.2 mm) dorsally after the surgeries. The spinal canal space narrowing showed an average 6.5 mm improvement postoperatively. Operative time averaged 2 hours and 34 minutes, and blood loss averaged 250 mL (range 150–400 mL). No neurologic complications and wound healing problems were observed.**

CONCLUSIONS: **The combination of MISS and whole-body traction provided successful anatomical correction in thirteen of the fifteen cases of compression type thoracolumbar fractures without extensive surgical exploration.**

INTRODUCTION

The treatment of a patient suffering from a severe spinal injury implies immense financial and social burdens on the health system, the patient, and the patient's and family members' quality of life.[1-3] Inappropriate treatment can lead to secondary nervous system injuries resulting in life-long consequences. In the last few decades, in the treatment of thoracolumbar injury classification and severity score 5–10 thoracolumbar fractures, surgical repair techniques came to the fore because of early surgical care, whereas conservative methods were applied to the treatment of elderly or multimorbid patients,[4] although controversies still exist.[5,6]

There are 3 main surgical therapeutic goals associated with unstable spine fractures: the decompression of the nerve structures, the correction of the traumatic deformity, and restoring stability to the spine while preserving the fracture reduction. Regarding surgical techniques, the aforementioned therapeutic goals can be completed in an open-direct or covered-indirect manner, depending on the type and severity of the fracture and neurologic state. Open approaches and direct decompression continue to be more prevalent worldwide, even when more patient-friendly and cost-effective methods are available.[7]

Key words
- Fracture
- Ligamentotaxis
- Minimally invasive spine surgery
- Traction

Abbreviations and Acronyms
AO: Classification by AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation
CT: Computed tomography
L.IV: Fourth lumbar vertebra
MISS: Minimally invasive spine surgery
Th.XII: Twelfth thoracic vertebra

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Figure 1. Whole-body traction is demonstrated: extension along the spine's longitudinal axis is generated by pulling the patient's shoulders and ankles. The precise placement of cushions below the chest and pelvis helps the reduction of the fractured spine.

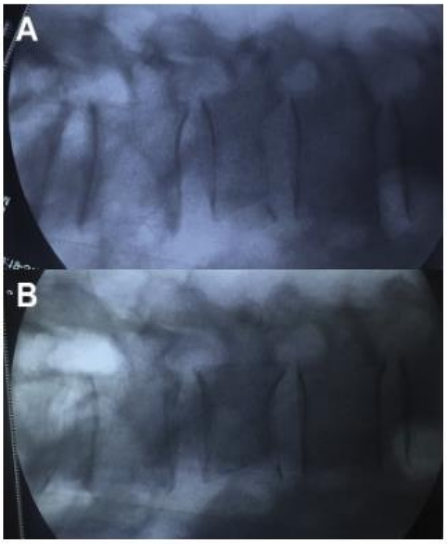

Figure 2. The sudden improvement of the traumatic kyphosis, traumatic spinal stenosis, and the fractured vertebral body's height is easily observed on the C-arm images taken in the operation room before (**A**) and after (**B**) whole-body traction.

In our paper, we would like to draw attention to an acute, indirect decompression method that involves the combination of whole-body traction and percutaneous pedicle screw fixation. The presented method can be used in AO A- or C-type compression thoracolumbar injuries.[8]

In terms of decompression and deformity correction, the principle of the method is closed reduction performed by traction, which has been well-known in many forms since Lorenz Böhler.[9] The concept of traction is widely known in the treatment of degenerative spine diseases, including the safe application in the treatment of childhood scoliosis.[10]

In the treatment of thoracolumbar spine fractures, ligamentotaxis has already been applied in several ways. In an open surgical approach, the ligamentotaxis was applied to achieve spinal canal decompression and reduce deformity.[11-18] Whole-body traction also has been applied to reduce spine fracture with severe dislocation, either preoperatively with halo-bifemoral traction for 48 hours[19] or intraoperatively by manual forces in open surgeries.[20]

Similar to ligamentotaxis in open surgeries performed by pedicular screws, whole-body traction ligamentotaxis is also performed and has proved beneficial in conservative monotherapy,[21] similar to Crutchfield's traction treatment of neck injuries.[22,23] In terms of restoring stability to the spine, percutaneous spinal fixation is as well known.

SURGICAL TECHNIQUE

As mentioned previously, 3 main therapeutic goals are associated with unstable spine fractures: decompression of the nerve structures and the correction of the traumatic deformity are achieved by whole-body traction. The third goal, restoring stability to the thoracolumbar spine while preserving the fracture reduction, is achieved by percutaneous pedicle screw fixation.

Planning

One of the most important parts of percutaneous spine surgery is meticulous planning. Bone windowed computed tomography (CT) pictures are preferred, which also depicts the patient's skin surface on the section concerned. Three measurements are necessary on both sides, for every affected level: the pedicle diameter, the length of the pedicular screws, and the distance of the incision from the midline.

Patient Positioning

We used Maquet Otesus Operating Table (Getinge Group, Getinge, Sweden) in all cases. Following the induction of general anesthesia and application of muscle relaxants, we carefully roll the patient to a prone position. Supportive cushions are applied below the chest and pelvis. It was regularly found that traumatic kyphosis can be partially corrected by the appropriate positioning of the pelvis and chest. The patient's arms are in a prone Superman position to avoid potential summation shadows. Patient positioning is followed by the whole-body traction.

Indirect Decompression with Whole-Body Traction

Ligamentotaxis is achieved by whole-body traction along the longitudinal axis of the spine by pulling the patient's shoulders and ankles or pelvis (**Figure 1**). If lower-limb trauma has occurred, the pelvis is pulled downward axially instead of the ankles. This procedure is carried out with a gradually increasing force manually for 20–30 seconds during the whole-body traction. Lateral fluoroscopy control is implemented during and following the whole-body traction to control the tractive force. The theoretical

Table 1. Comparison of Preoperative and Postoperative Measured Values of the Spinal Canal Diameter and Vertebral Body Height

Sex (F/M), Age at the Time of the Surgery (Years), Type of Fracture (AO Classification)	The Spinal Canal Diameter Preoperatively and Postoperatively, and the Difference Between Them, mm	The Vertebral Body Height Preoperatively and Postoperatively, and the Difference Between Them Ventrally, mm	The Vertebral Body Height Preoperatively and Postoperatively, and the Difference Between Them Dorsally, mm
1. M 51 L.I. AO C	5.0/11.5 6.5	17.0/38.9 21.9	25.4/36.6 11.2
2. F 65 L.I. AO A4	9.5/17.5 8	26.6/40.3 13.7	26.5/36.5 10
3. F 61 L.I. AO A3	10.0/16.1 6.1	24.0/36.4 12.4	28.1/33.0 4.9
4. M 18 L.III. AO A3	13.0	47.4	37.3
5. F 38 L.I. AO A4	8.1/14.3 6.2	17.5/32.8 15.3	24.4/31.8 7.4
6. M 57 L.II. AO A4	4.7/8.8 4.1	36.1/44.3 8.2	34.3/39.0 4.7
7. M 42 Th.XII. AO A3	12/16 4	30.0/44.5 14.5	35.4/41.0 5.6
8. F 67 Th.XII. AO A4	8.2/12.8 4.6	20.4/35.5 15.1	22.2/32.2 10
9. M 44 L.I. AO A4	8.5/10.6 2.1	30.8/38.6 7.8	35.1/38.2 3.1
10. F 76 L.I. AO A4	6.6/10.2 3.6	19.7/29.1 9.4	25.2/29.4 4.2
11. M 29 Th.XII. AO C	2.1/10.8 8.7	22.9/36.8 13.9	30.3/35.1 4.8
12. M 38 Th.XII. AO C	0/14.6 14.6	27.0/39.3 12.3	35.0/35.6 0.6
13. M 64 Th.XII. AO C	0.9/7.5 6.6	27.9/31.9 4.0	29.8/33.5 3.7
14. F 46 L.I. AO A2	13.8/16.4 2.6	32.2/37.1 4.9	33.2/34.1 0.9
15. M 20 L.IV. AO A4	1.5/5.4 3.9	39.5/43.4 3.9	31.2/39.5 8.3

F, female; M, male; AO, Classification by AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation; L, lumbar; Th, thoracic.

possibility of "overstretching" is prevented by fracture selection (i.e., only compression injuries) and radiograph control during whole-body traction. Often, maximum human strength is necessary. If and when required, the maneuver can be repeated several times. Typically, substantial improvements can be noticed on C-arm images regarding the vertebral body's height, traumatic kyphosis, and traumatic spinal stenosis (**Figure 2**). Time does not seem to have a substantial effect on whole-body traction in the operating room in relaxed patients under general anesthesia, but the movement of the patient does. For this reason, whole-body traction was immediately followed by minimally invasive spine surgery (MISS) of the spine. Only immediate post-traction spinal fixation can ensure that the effect of whole-body traction is not reduced.

Implants

The Longitude II system (Medtronic, Minneapolis, Minnesota, USA) was used in all cases. Bilateral polyaxial cannulated titanium pedicle screws of 5.5 to 7 mm in diameter were used in every case. In our opinion, usually, 4 pedicle screws above the fracture and 4 pedicular screws below the fracture provide adequate stability. So usually, 10 screws are used, including the fractured vertebra. At a younger age, a shorter construct can be sufficient with adequate bone quality. We used 5.5-mm straight titanium rods in every case

Table 2. Comparison of Preoperative and Postoperative Measured Values of the Traumatic Kyphosis

Sex (F/M), Age at the Time of the Surgery (Years), Type of Fracture (AO Classification)	The Traumatic Kyphosis Preoperatively and Postoperatively, and the Difference Between Them (Degrees)
1. M 51 L.I. AO C	+8.4/−6.5 14.9
2. F 65 L.I. AO A4	+13.7/0 13.7
3. F 61 L.I. AO A3	+17.5/0.7 16.8
4. M 18 L.III. AO A3	−16.4
5. F 38 L.I. AO A4	+14.2/−9.3 23.5
6. M 57 L.II. AO A4	+6.7/+2.7 4.0
7. M 42 Th.XII AO A3	+23.6/+2.7 20.9
8. F 67 Th.XII AO A4	+7.5/+6.1 1.4
9. M 44 L.I. AO A4	+18.2/+3.4 14.8
10. F 76 L.I. AO A4	+21.0/+7.7 13.3
11. M 29 Th.XII AO C	+19.6/+6.4 13.2
12. M 38 Th.XII AO C	+21.5/+4.4 17.1
13. M 64 Th.XII AO C	+20.5/+8.5 12.0
14. F 46 L.I. AO A2	+6.7/+0.2 6.5
15. M 20 L.IV AO A4	−21.3/−15.4 5.9

F, female; M, male; AO, Classification by AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation; L, lumbar; Th, thoracic.

contoured intraoperatively to match the given curvature and preserve the correction of traumatic kyphosis gained with proper patient positioning and whole-body traction.

Implantation of the Pedicle Screws and Rods

Percutaneous minimally invasive fixation was performed immediately after whole-body traction as follows. We usually go from cranial to caudal during the implantation. An incision 2 cm long is made at the measured distance from the midline. Careful hemostasis can prevent wound healing disorders such as seromas. A bone biopsy needle is implanted with fluoroscopic guidance followed by Kirschner wire as a guidewire. Drilling may be necessary, especially in younger patients with hard bones or in the case of seriously damaged vertebrae. If the injured vertebra composed of fragments, we don't implant a screw between fragments. If half of the vertebra is considered intact, a screw is implanted on the intact side, and we skip the fragmented part. It is important to mention the importance of implanting in order the screw tulips regarding the depth and the distance from the midline. Even with polyaxial screws, the rod emplacement can be challenging if the screw tulips stand at different heights or not in line. The rod implantation is mostly done from cephalad to caudal direction. An overhang of up to 1 cm at both ends is acceptable, checked by lateral and anteroposterior fluoroscopy. In our practice, there has been no example so far that the effect of the whole-body traction during MISS is reduced. For this reason, no traction is applied again before tightening the rod fixing bolts.

Wound Closure

The fascia is closed with #2 VICRYL plus antibacterial interrupted sutures. After suturing the subcutaneous tissue with 2-0 VICRYL absorbable interrupted sutures, the skin is also closed with 4-0 absorbable continuous intracutaneous sutures.

Postoperative Care

The day after surgery, the patient is mobilized with the aid of physiotherapists. If the patient has paraplegia due to the trauma, gradual seating should be attempted. The thrombosis prophylaxis is essential. After 1 year of the surgery, removing instrumentation is proposed, especially in cases of younger patients. If the CT follow-up refers to healing and the patient approved the removal of the instrumentation, the same incisions are used to remove the screws.

METHODS

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments. Informed consent was obtained from all individual participants included in the study. Fifteen patients meeting the following eligibility criteria were operated sequentially with the combination of whole-body traction and percutaneous minimally invasive spine fixation. Thoracolumbar injuries AO A-type and AO C-type without distraction origin were included. Data were analyzed retrospectively. The following measurements were made on the preoperative and postoperative CT scans.

The traumatic kyphosis was measured as the angle between the upper adjacent vertebral body's upper endplate and the lower adjacent vertebral body's lower endplate. The vertebral height was measured as the distance between the ventral–caudal corner of the upper adjacent vertebral body and the ventral–cranial corner of the lower adjacent vertebral body. The same measurements were performed on the dorsal side of the vertebral body. The anteroposterior diameter of the spinal canal was measured at the narrowest level in the median sagittal plane on preoperative CT scans. The same points were measured on the postoperative CT scans.

Table 3. Neurologic State

Sex (F/M), Age at the Time of the Surgery (Years), Type of Fracture (AO Classification)	Preoperative Neurologic State	Postoperative Neurologic State	Final Neurologic State
1. M 51 L.I AO C	Intact	Intact	Intact
2. F 65 L.I AO A4	Intact	Intact	Intact
3. F 61 L.I AO A3	Intact	Intact	Intact
4. M 18 L.III AO A3	Intact	Intact	Intact
5. F 38 L.I AO A4	Intact	Intact	Intact
6. M 57 L.II AO A4	Intact	Intact	Intact
7. M 42 Th.XII AO A3	Intact	Intact	Intact
8. F 67 Th.XII AO A4	Distal type paraparesis: knee extension: 4/5 (both), dorsalflexion: 2/5 (left), and 3/5 (right), plantarflexion: 2/5 (left) and 3/5 (right). Diffuse distal type pareaesthesia (numbness). Bladder and spinchter ani function intact. No Babinski sign.	Improved distal type paraparesis: knee extension: 5/5 (both), dorsalflexion: 3/5 (left), and 4/5 (right), plantarflexion: 3/5 (left) and 4/5 (right). Diffuse distal type pareaesthesia (numbness) slightly improved. Bladder and spinchter ani function intact. No Babinski sign.	Slight paresis only on the left side distally: dorsalflexion 4/5, plantarflexion 4/5. Sensory function intact. Bladder and spinchter ani function intact. No Babinski sign.
9. M 44 L.I AO A4	Intact	Intact	Intact
10. F 76 L.I AO A4	Intact	Intact	Intact
11. M 29 Th.XII AO C	Paraplegia Total sensory loss on lower limbs, niveau in the L.1 dermatome (mons pubis). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. Babinski sign on the left side.	Paraplegia Sensory loss on lower limbs, niveau in the L.3 dermatome (middle of the thighs). Areflexia of the lower limbs. Bowel and bladder function loss. Babinski sign on the left side. Lower-limb areflexia.	Paraplegia Sensory loss on lower limbs, niveau in the L.3 dermatome (middle of the thighs). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.
12. M 38 Th.XII AO C	Paraplegia Total sensory loss on lower limbs, niveau in the Th.10 dermatome (navel). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.	Paraplegia Total sensory loss on lower limbs, niveau in the Th.10 dermatome (navel). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.	Paraplegia Total sensory loss on lower limbs, niveau in the Th.10 dermatome (navel). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.

F, female; M, male; AO, Classification by AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation; L, lumbar; Th, thoracic.

Continues

Table 3. Continued

Sex (F/M), Age at the Time of the Surgery (Years), Type of Fracture (AO Classification)	Preoperative Neurologic State	Postoperative Neurologic State	Final Neurologic State
13. M 64 Th.XII AO C	Paraplegia. Total sensory loss on lower limbs, niveau in the L.1 dermatome (mons pubis). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.	Paraplegia. Total sensory loss on lower limbs, niveau in the L.1 dermatome (mons pubis). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.	Paraplegia. Total sensory loss on lower limbs, niveau in the L.1 dermatome (mons pubis). Areflexia of the lower limbs. Bowel and bladder function loss. Lower-limb areflexia. No Babinski sign.
14. F 46 L.I AO A2	Intact	Intact	Intact
15. M 20 L.IV AO A4	Only sensory disorder: numbness on the left side in the L.5 dermatome	Only sensory disorder: slight numbness on the left side in the L.5 dermatome	Intact

F, female; M, male; AO, Classification by AO (Arbeitsgemeinschaft für Osteosynthesefragen) Foundation; L, lumbar; Th, thoracic.

The operative time and blood loss were recorded. Besides the extremity neurologic function, the bladder and bowel function were assessed. No additional instrumented ligamentotaxis was necessary in the cases. No neuromonitoring was applied, since it is not possible in acute cases in our department.

RESULTS

The presented whole-body traction combined with percutaneous spine fusion was performed in 15 patients (6 female, 9 male) with spine trauma injured from compression forces. The average age of the patients was 47 years old (range 20–74 years). Vertebral fractures developed in the following distribution: twelfth thoracic vertebra (Th.XII): 5, first lumbar vertebra (L.I): 7, second lumbar vertebra (L.II): 1, third lumbar vertebra (L.III): 1, and fourth lumbar vertebra (L.IV): 1. A total of 139 screws were implanted into 70 segments. In the case of 3 older patients, screw implantation was combined with vertebroplasty augmentation. In 2 cases, we performed one-level laminectomy also.

Clinical follow-up averaged 16 months. One patient underwent surgery 4 months before the article submission. One of our patients was lost for the 12-month follow up.

The spinal canal space narrowing showed an average 6.5 mm (range 2.6–14.3 mm) postoperative improvement. The fractured vertebrae's height gain was an average of 11.0 mm (range 3.9–21.9 mm) ventrally and an average of 5.4 mm (range 1–11.2 mm) dorsally after the surgeries (Table 1).

Preoperative traumatic kyphosis was experienced in 14 cases with an average preoperative kyphosis of 17 degrees and an average postoperative kyphosis of 1.8 degrees (Table 2). In the only L.IV fracture, preoperative kyphosis of −21.3 degrees and postoperative kyphosis of −15.3 degrees were measured.

Operative time averaged 2 hours and 34 minutes (range 70–325 minutes), and blood loss averaged 250 mL (range 150–400 mL). The average hospital stay was 6 days (range 4–9 days). No neurologic complications were observed, and we didn't experience wound healing problems. Eleven patients were neurologically intact or had a slight neurologic disorder (Table 3), such as temporary numbness (Figures 3 and 4).

One patient suffered a severe paraparesis with diffuse numbness and unimpaired vegetative function: she was a 67-year-old woman who fell down the stairs and suffered an unstable Th.XII. vertebral body fracture (A type by AO classification). One level laminectomy followed the whole-body traction, then percutaneous pedicle screw fixation was performed with 10 screws. On the 10-month follow-up, she walked on her own feet with a cane. Slight distal paresis was found on the left side (Figure 5). Three patients suffered transverse lesion with paraplegia, total sensory loss on lower limbs, and bowel and bladder function loss (Figure 6).

Among the 15 cases, the ligamentotaxis showed slight effectiveness in restoring spinal canal narrowing in 2 cases, although traumatic kyphosis and height reduction were corrected in these cases. One of them was a 20-year-old male patient struck by a heavy log and suffered an AO C-type L.IV fracture (Figure 7). However, despite the frightening-looking CT scans, the young patient was miraculously neurologically intact, so laminectomy was omitted. The only complaint was slight numbness in the L.4 dermatome left side, which had disappeared at the 3-month follow-up.

The other case was a 64-year-old man who was hit by a car. The patient suffered an unstable Th.XII. vertebral body fracture (C type by AO classification), associated with serious spinal canal stenosis (Figure 8). The complete transverse lesion with paraplegia developed at the moment of the accident. In our opinion, we do not see the benefit of the decompression in complete neurologic

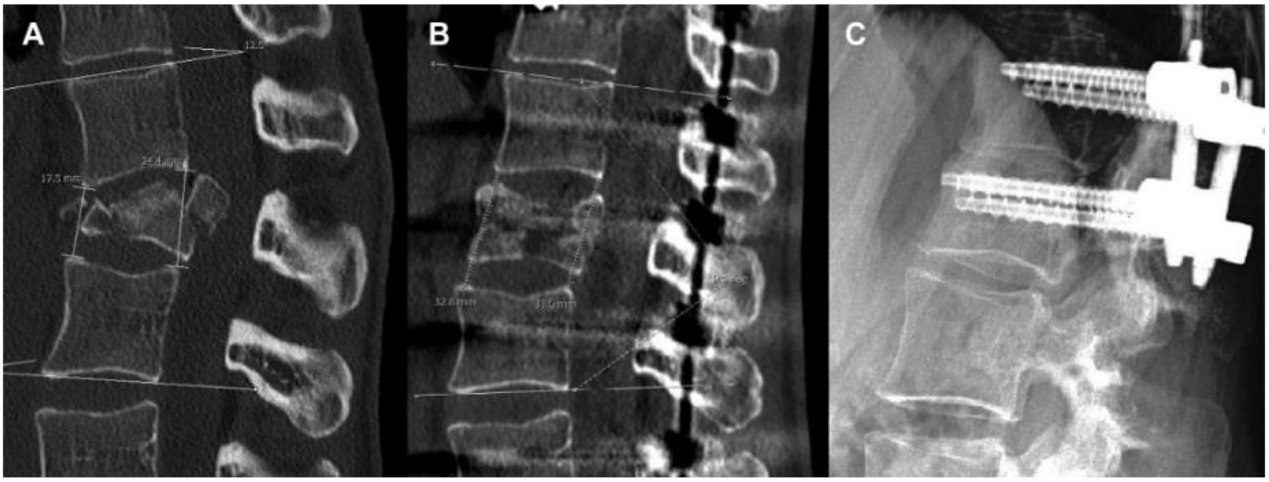

Figure 4. An AO A-type first lumbar vertebra injury was occurred because of a traffic accident. The first image (**A**) depicts a bone fragment narrowing the spinal canal, which later rotated back to its original position following successful whole-body traction (**B**). The radiograph image (**C**) exhibits the final result 1 year following surgery: partial screw removal, short-segment fixation, and dorsal fusion were applied. The patient is neurologically intact.

deficit (acute paraplegia, Frankel A) resulting from severe spine fracture dislocation (e.g., **Figures 8** and **9**).

At 18-month follow-up, CT and magnetic resonance imaging scans were performed. The latter still not depicted the development of syrinx, the patient's neurologic state was unchanged. Follow-up of the patient continues.

DISCUSSION

The combination of whole-body traction and MISS can be applied safely and effectively for the acute treatment of spinal trauma resulting from compression forces throughout the spine, including the sacral region; nevertheless, the number of relevant publications is limited.[24] The combination of MISS and instrumental ligamentotaxis is often cumbersome due to the limited access of the procedure and the inappropriate MISS tools for fracture reduction. Usually, only polyaxial screws are available for MISS that also reduces the capabilities of MISS tools for fracture reduction.

The authors aimed at solving this issue by the reinvention of whole-body traction (i.e., extracorporeal ligamentotaxis). The indirect decompression provided by the extracorporeal ligamentotaxis not only increases the height of the fractured vertebral body and the neuroforamen, but the correction of the traumatic kyphosis and spinal canal stenosis is also discernible. The integrity regarding the spinal ligament system is crucial for ligamentotaxis. Only fractured bony fragments still attached to the posterior longitudinal ligament can be repositioned. These fragments are usually located in the midline and joined to the superficial part of the posterior longitudinal ligament. Fragments located in the lateral position are typically attached only to the deep layer of the posterior longitudinal ligament; thus, the effect of extracorporeal ligamentotaxis among these elements proves to be less efficient.[11,12]

Stabilizing the spine through the implementation of minimally invasive methods following extracorporeal ligamentotaxis is largely advantageous in patients with polytrauma (**Figure 9**). It helps to reduce operation time, blood loss, and infection risk. It also eliminates the risk of a potential cerebrospinal fluid leak after surgery. Usually, there is no need for extensive open surgeries in patients with polytrauma.

Whole-body traction is not recommended in specific cases: the mechanism of injury or the radiologic signs suggest ligamentous injury. So, it is clearly contraindicated in distraction type injuries (type B by AO classification). In clear compression injuries (type A) by AO classification, the method is well suited. It is also well applicable for type C injuries; however, type C injuries with distraction origin by AO classification require caution.

The presented method is recommended in patients without neurologic signs or with slight neurologic impairment. In patients showing more severe neurologic deficits, the application of the method is a matter of individual consideration unless a rupture of the spinal cord is evident (**Figure 9**). In cases of severe neurologic impairment, a supplementary laminectomy at the level of the traumatic stenosis can be beneficial.

Caution should be considered when the patient is suffering from a multitude of injuries, such as in the case regarding polytrauma, e.g., pelvis fractures form an absolute contraindication of the method. It also should be noted that sometimes only partial correction can be achieved, similar to conventional open ligamentotaxis. This partial fracture reduction is still beneficial and further corrections can be attempted with distraction tools during surgery. However, according to the authors' experience, usually, no further correction can be achieved by MISS fracture reduction tools after whole-body traction. It is believed that whole-body

traction is much more physiological than conventional ligamentotaxis, in which, transpedicular screws are pushed against the healthy adjacent segments and sometimes pedicles can break during the distraction maneuver.

CONCLUSIONS

In most cases, the combination of extracorporeal ligamentotaxis and minimally invasive spine surgery proves to be an effective, simple, rapid, safe, and cost-effective solution regarding the surgical treatment of AO A- or C-type fractures resulting from compression forces obviating the use of dedicated polyaxial screws and internal traction devices. Further studies are needed to prove the results of our pilot study presenting only a small number of cases.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Viktor Szabó: Writing – original draft, Project administration, Investigation, Software. **Máté Nagy:** Writing – review & editing, Formal analysis. **András Büki:** Writing – review & editing. **Attila Schwarcz:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition, Supervision.

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MINIMÁLISAN INVAZÍV, EXTRAPLEURALIS, ANTEROLATERALIS GERINCFELTÁRÁS

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A gerincsebészetben, más sebészi területekhez hasonlóan, az elmúlt évtizedekben világszerte a minimálisan invazív eljárások előretörése tapasztalható. A minimálisan invazív eljárásokkal bizonyítottan csökkenthető a műtéti vérvesztés, a gennyedés kockázata, a műtét utáni fájdalomszint és a beteg kórházi tartózkodásának ideje. Jelen cikkünkben a Magyarországon újdonságnak számító minimálisan invazív anterolateralis extrapleuralis gerincfeltárást mutatjuk be. Szemben az elterjedt costotransversectomiával a minimálisan invazív feltárás direkt rálátást enged a durazsák ventralis felszínére, valamint a műtét után nem szükséges mellkasi drenázs alkalmazása és intenzív osztályos kezelés. A módszer biztonsággal alkalmazható a thoracalis gerincszakasz ventralis, ventrolateralis kórfolyamataiban.

Kulcsszavak: *gerinc, extrapleuralis, retropleuralis, minimálisan invazív*

MINIMALLY INVASIVE, EXTRAPLEURAL-ANTEROLATERAL APPROACH TO THE SPINE

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In spine surgery, minimally invasive approaches (MIS) are getting accepted and more popular worldwide during the last decades. It is due to the reduced intraoperative blood loss, decreased infection rate, less postoperative pain and earlier discharge from hospital compared to traditional approaches. The present paper puts forward a minimally invasive extrapleural approach to the thoracic spine that is not applied in Hungary. This new approach, in contrast to the standard costotransversectomy, provides direct visual control over the ventral surface of the dural sac. Furthermore, contrary to the transthoracic way, following minimally invasive extrapleural surgery thoracic drainage and intensive care are not necessary. The approach can be applied safely in treatment of ventral or ventrolateral pathologies of the thoracic spine.

Keywords: *spine, extrapleural, retropleural, minimally invasive*

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Bevezetés

A thoracalis gerincsebészet nehézségeit jól jelzi, hogy a nevezett gerincszakasz sebésztechnikai fejlődése több mint egy évszázadra tekint vissza, és jelenleg is zajlik. A kihívást elsősorban azok a kórképek jelentik, amelyek esetében a gerincvelő ventralis-ventrolateralis dekompressziójára van szükség. Az évtizedek során több megközelítési irány alakult ki a thoracalis gerincszakasz feltárásaihoz: eleinte a hagyományos, hátsó behatolás (posterior megközelítés) volt a beavatkozások kiindulópontja, majd később a csigolyák posterolateralis, lateralis, illetve anterolateralis irányból történő megközelítése fejlődött ki, javarészt párhuzamosan.

Az esetleges szövődmények, a technikai fejlődés, továbbá az öregedő társadalom által az egészségügyre gyakorolt egyre nagyobb logisztikai és financiális nyomás, más szakterületekhez hasonlóan, a gerincsebészetben is kialakította a minimáli-

san invazív eljárások iránti folyamatosan növekvő igényt[1].

Az extrapleuralis (másnéven retropleuralis) eljárások már egészen korán leírásra kerültek, azonban a szakmai köztudatba *McCormick* közlése után kerültek be, alig több mint két évtizede[2]. Jelen cikkünk célja a minimálisan invazív anterolateralis extrapleuralis gerincfeltárás hazai bemutatása. A bevezető többi részében az eddig elterjedt hagyományos thoracalis gerincfeltárásokat és az általunk hazánkban bevezetett minimálisan invazív anterolateralis extrapleuralis gerincfeltárást ismertetjük.

POSTERIOR MEGKÖZELÍTÉS

A hátsó feltárások közül legkorábban a dekompresszív laminectomia vált ismertté a XIX. század végén[3]. Jó ideig standard eljárásnak számított, annak ellenére, hogy magas morbiditási mutatókkal bírt, elsősorban a thoracalis gerincvelőszakasz mozgatásából adódó ártalmak miatt[4–8]. A feltárást a mai gyakorlatban legtöbbször a thoracalis gerincmetasztázisok vagy intraduralis daganatok eltávolítására használják.

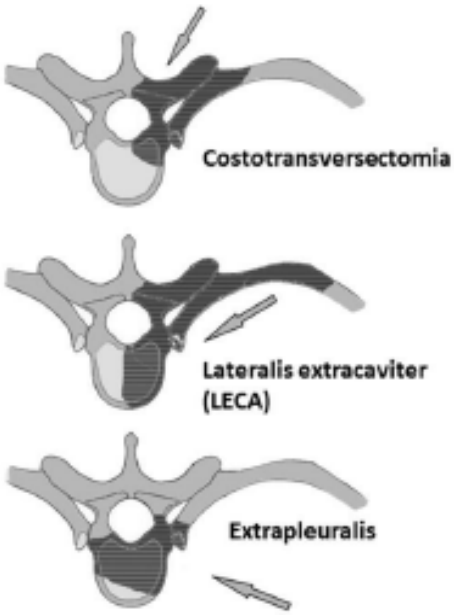
A thoracalis gerinc hátulsó megközelítésénél is alkalmazhatók a *Banczerowski* és munkatársai által kifejlesztett minimálisan invazív technikák[9].

A posterior transduralis feltárást 2010-ben közölték. Elsősorban a thoracalis szakasz centrális sérveinek a megoldására kínálhat alternatívát. A módszer objektív megítélése az alacsony közölt esetszám miatt egyelőre várat magára[10, 11].

POSTEROLATERALIS MEGKÖZELÍTÉS

A posterolateralis megközelítések leginkább elterjedt változatát, a costotransversectomiát *Hulme* közölte 1960-ban[12]. Az egy- vagy kétoldali costotransversectomia legfőbb indikációját a csigolyaáttétek sebészi ellátása adja[5, 13], azonban jól használható akkor is, ha a gerincvelő anterolateralis dekompressziójára van szükség, például egy porckorongsérv esetében. A costotransversectomia során a beteg hason vagy 15-20 fokban elfordított, hason fekvő pozícióban helyezkedik el a műtőasztalon. A két pediculus által kijelölt síkban történik a műtét. Általában a dura oldalsó és ventrolateralis felszíne is látótérbe hozható. Többnyire a borda proximalis pár centiméteres szakasza, az adott oldali lamina és kisízület, valamint ennek megfelelően a csigolyatest fovea costalist tartalmazó részlete kerül eltávolításra[14, 15]. A kórfolyamat elhelyezkedésétől függően a bordareszekció válogatott esetekben elkerülhető[16].

Az eljárás fő hátránya, hogy a durazsák elülső felszínére nem enged direkt rálátást, szemben az anterolateralis feltárásokkal **(1. ábra)**. Továbbá az esetlegesen ellenoldalon is jelen lévő kórfolyamat egy oldalról nem elérhető. Szintén kedvezőtlen, hogy a szegmentális artériákból vérzés indulhat egy corpectomia során, és a limitált betekintési szög miatt a vérzés csillapítása nehézkes lehet[17].



1. ábra. *A közleményben bemutatott thoracalis gerincfeltárások típusait mutatja az ábra. Nyilak jelzik, hogy milyen szögben történik a rálátás a durazsákra egy dekompresszió során. A besatírozott részek pedig azt szemléltetik, hogy az adott feltárásból a csigolyák mely részei érhetők-távolíthatók el egy műtét során*

LATERALIS MEGKÖZELÍTÉS

Külföldön az utóbbi néhány évtizedben terjedt el a lateralis irányból való direkt megközelítés **(1. ábra)**. A lateralis extracaviter megközelítést (lateral extracavital approach, LECA) elsőként *Larson* és munkatársai közölték 1976-ban[18].

Az eljárás során a costotransversectomiához hasonlóan a fali pleura megtartása a cél, azonban a feltárást, és szükség szerint a bordareszekciót lateralisabban kiterjesztik. Így a háti csigolyák lateralis oldalról közelíthetők meg anélkül, hogy a mellüregbe vagy a thoracolumbalis átmenet sebészete során

a hasüregbe hatolnánk, a feltárás a peritoneumzsákon és a fali pleurán kívül történik. Ez gyorsabb felépülést eredményez. Amellett, hogy jól láthatóvá teszi a dura ventrolateralis részét, szükség esetén, megfelelően vezetett metszésvonallal egy ülésben hátsó rögzítés is végezhető[19]. A LECA-feltáráshoz általában dorsalisan a középvonalban vezetett hosszú metszés szükséges, és a paravertebralis izomzat leválasztása és mobilizációja szintén elkerülhetetlen. A LECA-feltárást a gerinc daganatainak eltávolításánál, illetve deformitáskorrekció céljából végzett corpectomia esetében használják leggyakrabban. A feltárás különösen kedvező abban az esetben, ha a daganat paravertebralisan is terjed.

ANTEROLATERALIS MEGKÖZELÍTÉS – TRANSTHORACALIS THORACOTOMIA

A costotransversectomia elterjedése után nem sokkal *Perot* és *Munro* írta le az anterolateralis megközelítésű transthoracalis thoracotomia módszerét[20]. A thoracotomia direkt rálátást biztosít a csigolyák elülső-oldalsó felszínére anélkül, hogy a paravertebralis izomzatot leválasztanánk és mobilizálnánk. Az eljárás hatékonyan alkalmazható a gerinc elülső oszlopát érintő kórfolyamatok esetében: például a csigolyatest daganatos, degeneratív vagy gyulladásos elváltozásai során. Gerinctrauma és thoracalis porckorongsérv kezelésében is egy jól használható megközelítést jelent.

A dorsalis és lateralis megközelítésekhez képest jobb rálátást biztosít a dura teljes ventralis felszínére. A módszer hátránya, hogy a thoracotomia miatt szövődmények fordulhatnak elő, mint tüdősérülés, pneumonia, haemothorax. A feltárás során mindig keletkezik pneumothorax, azaz a posztoperatív időszakban 2-3 napra mellkascső behelyezése szükséges és a beteg ennek megfelelően intenzív osztályos elhelyezést igényel. Az esetleges liquorszivárgást pedig a szokásosnál is szigorúbban kell venni thoracotomiás feltárás során: a negatív mellűri nyomás liquorfistulát tarthat fenn, mely kezelése hosszadalmas, és körülményes lehet[21].

ANTEROLATERALIS MEGKÖZELÍTÉS – MINIMÁLISAN INVAZÍV ANTEROLATERALIS EXTRAPLEURALIS THORACOTOMIA

A minimálisan invazív anterolateralis extrapleuralis gerincfeltárás **(1. ábra)** előnye a hátulsó feltárásokkal szemben, hogy direkt rálátást biztosít a gerinc elülső-oldalsó részére, így a gerincvelő elülső dekompressziója megfelelő vizuális kontroll mellett végezhető. A retropleuralis feltárásnak köszönhetően nem szükséges a műtét után mellkascső behelyezése, ezáltal a 2-3 napos intenzív osztályos kezelés is elkerülhető. A pleuraűr intakt marad, így haemothorax sem alakulhat ki. A betegek már a műtét másnapján mobilizálhatók, ennek megfelelően a betegek emissziója is több nappal korábban megtörténhet szemben a hagyományos thoracotomiás feltárásokkal. Az extrapleuralis feltárás indikációi megegyeznek a transthoracalis thoracotomia indikációival.

Esetismertetések

Ebben a fejezetben néhány eseten keresztül a thoracalis gerincfeltárások fő fajtáit szeretnénk bemutatni: 1. hagyományos costotransversectomia, 2. lateralis extracaviter megközelítés (LECA), 3. minimálisan invazív extrapleuralis thoracotomia. A hazai környezetben újdonságnak számító minimálisan invazív anterolateralis extrapleuralis gerincfeltárás létjogosultságát több eset bemutatásával szeretnénk hangsúlyozni.

COSTOTRANSVERSECTOMIA

Az extrémen obes (testsúly 123 kg) nőbeteget akutan romló, progresszív paraparesis miatt vettük fel osztályunkra. Felvétele előtt két héttel álló helyzetből összeesett, ezt követően lábait gyengébbnek érezte. Ez a gyengeség fokozódott, felvételekor járásképtelen volt. Deréktól lefelé zsibbadásról, érzéketlenségről számolt be.

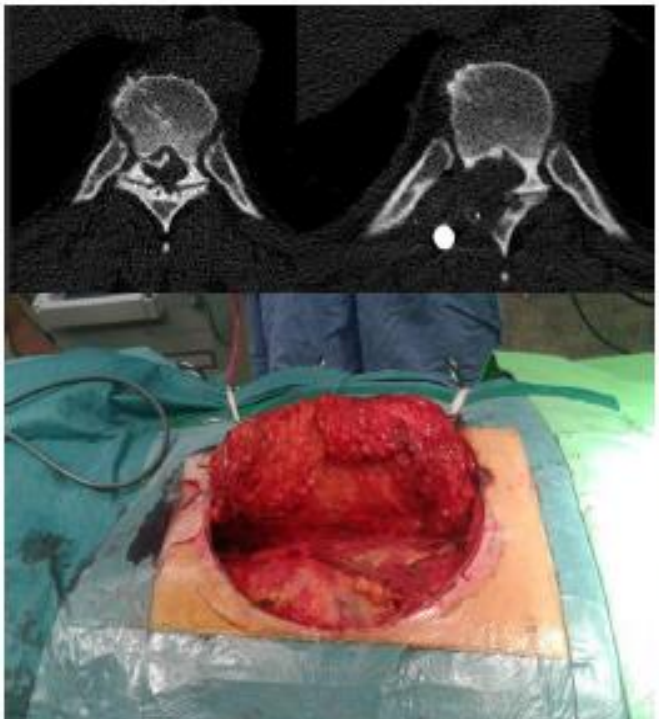
Státuszából kiemelendő az alsó végtagok bal oldali túlsúlyú, 2/5 súlyosságú paraparesise, továbbá fokozott alsó végtagi mélyreflexek, kétoldali Achilles-clonisatio, kétoldali Babinski-jel. A thoracalis IX-es szegmenttől distalisan hypalgaesiát jelzett. Vegetatív zavart a beteg nem tapasztalt.

A gerinc-MR- és -CT-vizsgálat Th.VII. magasságban gerincvelőt jelentősen komprimáló, myelopathiát okozó porckorongsérvet mutatott **(2. ábra)**. A koponya MR-vizsgálata agyállományi kóros jelintenzitás-változást nem írt le.

Tekintettel arra, hogy a meszes porckorongsérv inkább lateralisan helyezkedett el, illetve figyelembe véve a beteg súlyos obesitasából adódó extrém mellkaskörfogatot (azaz nem álltak rendelkezésre elegendően hosszú műszerek egy anterolateralis megközelítéshez), a betegnél a hagyományos costotransversectomiás feltárást választottuk. A műtét során bordareszekció végül nem vált szükségessé.

Műtéti módszer

Tekintettel az extrém obesitasra, egy középvonalat éppen meghaladó, jobb oldalra körülbelül 6 cm-ig



2. ábra. *A CT-képeken (felső sor) a Th. VII. magasságban elhelyezkedő, myelopathiát okozó meszes porckorongsérv ábrázolódik. A jobb oldali axiális kontroll-CT-felvételen látható, hogy a porckorongsérv meszes része is elfúrásra került. Az alsó műtéti képen a jobb oldali patkó alakú metszés látható. A patkó alakú metszésre azért volt szükség, hogy a 4 cm vastagságú subcutan zsírréteg (MR-képeken mérve) ne akadályozza a gerinc oldalsó-hátsó felszínére a rálátást, egy oldalra történő eltartás során. Az oldalról való betekintés feltétlenül szükséges volt a középvonalig terjedő, ventralis osteophyta biztonságos elfúrásához. A képen a m. latissimus dorsi alsó része is látható a feltárás közepén*

terjedő, körülbelül 10 cm-es alappal rendelkező patkó alakú metszést ejtettünk a Th. VII. porckorongra centrálva. Mivel a subcutan zsírréteget és a bőrt középvonal felé, medial felé hajtottuk ki a patkó alakú metszés alapjához, így oldalt a több centiméter vastag subcutan zsírréteg nem akadályozta a rálátást a gerinc oldalsó-hátsó felszínére **(2. ábra)**.

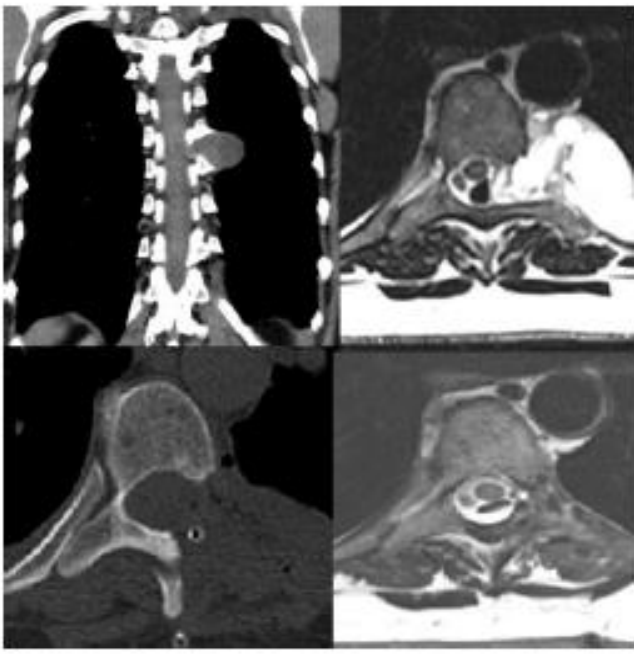
Ezt követően subperiostealisan választottuk le a paravertebralis izomzatot, majd lateral felé tartottuk el. A Th. VII–VIII. közötti facetet, illetve a Th. VIII. processus transversus egy részét és a Th. VII. pediculust eltávolítva a Th. VII-es discust feltártuk. Bordareszekcióra nem volt szükség. Mikroszkóp alatt megnyitva a gerinccsatorna lateralis részét a myelon elé tudtunk fúrni, így a porckorongsérvet a meszes osteophytával együtt el tudtuk távolítani. Tekintettel a teljes Th. VII–VIII. facetectomiára, illetve a beteg komoly túlsúlyára és a gerinc elülső oszlopának a meggyengülésére (discectomia), Th. VII–IX. egyoldali rögzítést végeztünk transpediculáris csavaros rudas rendszer segítségével. Kontrollképeken látható a meszes porckorongsérv eltávolítása **(2. ábra)**. A műtét után hat héttel, a kontrollvizsgálaton, már járóképes volt a beteg, parapa-resise minimálisra csökkent, az alsó végtagi zsibbadás teljesen megszűnt.

LATERALIS EXTRACAVITER MEGKÖZELÍTÉS (LECA)

A középkorú betegnek mellékleletként, tüdőszűrőn derült fény bal oldali homokóra-daganatára. A betegnek a daganat panaszt nem okozott, de a daganat eltávolítását szerette volna. A daganat Th. VIII. csigolya magasságában helyezkedett el, mind a gerinccsatorna, mind a mellűr felé lateralisan terjedt **(3. ábra)**. Így a daganat elhelyezkedése miatt a LECA-módszer tűnt a legmegfelelőbbnek. A bőrmetszés itt is patkó alakú volt, hasonlóan az előző esethez. A patkó alakú bőrmetszéssel a daganat lateralis széle könnyebben elérhető.

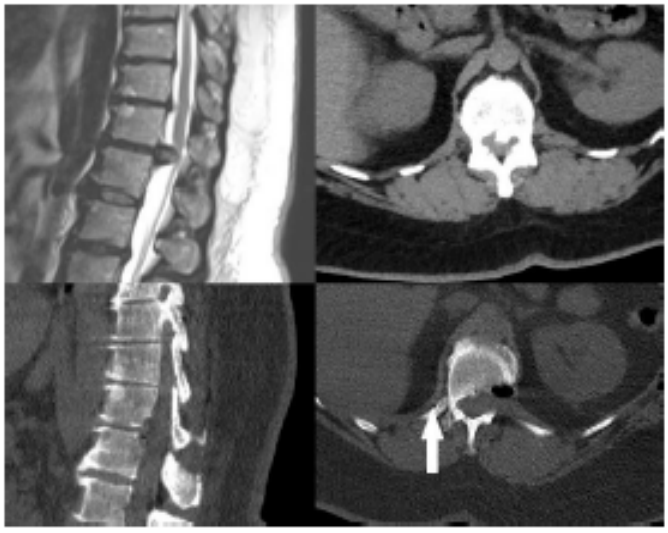
Műtéti módszer

Th. VIII. csigolyatest mellett elhelyezkedő daganat a műtét közbeni anteroposterior röntgenképeken is



3. ábra. *A bal oldali képeken jól látható a Th. 8. ideggyökből kiinduló, homokóraszerűen elhelyezkedő bal oldali schwannoma. A jobb oldali képeken látható a schwannoma eltávolítása utáni állapot: a Th. VIII. lamina, pediculus, processus transversus és a VIII-as borda egy része is eltávolításra került. A lateralis extracaviter megközelítés a durazsák elülső felszínére nem enged direkt rálátást, főleg a gerincoszlop oldalán elhelyezkedő kórfolyamatok esetében alkalmazható biztonsággal*

ábrázolódott. Így a daganatra centrálva a bal oldalon, a középvonaltól 5 cm-re érő enyhén ívelt, összesen körülbelül 10 cm hosszú, patkó alakú metszést ejtettünk. A fasciaréteg felett a bőrt és subcutan zsírt külön választottuk le és medial felé kihajtottuk. Ezután a processus spinosusok bal oldalán, subperiostealisan az izomzatot leválasztottuk, és eltartottuk, majd Th. VIII–IX. facetectomiát végeztünk. Láthatóvá vált a foramenben elhelyezkedő schwannoma. A daganatot az intraduralis terjedéssel együtt medial felől eltávolítottuk, majd duraplasztikát végeztünk. A lateralis rész felszabadításához a Th. VIII. csigolya processus transversusát és a VIII-as és IX-es bordák egymás felé néző részeit is eltávolítottuk. A daganat distalis részénél az ideggyököt éppen átvágva pleurát megőrizve a daganat egyben eltávolítható volt. Tekintettel a beteg vékony testalkatára, illetve a gerinc elülső oszlopának sértetlenségére, gerincrögzítést nem alkalmaztunk. A posztoperatív kontroll-CT- és -MR-vizsgálat a daganat *in toto* eltávolítását megerősítette **(3. ábra)**, pneumothorax nem volt látható. A műtét után a betegnek neurológiai kórjele nem alakult ki, átmenetileg volt a műtéti területnek megfelelően lokális fájdalma, később ez is megszűnt.



4. ábra. *A műtét előtti MR- és CT-felvételeken (felső sor) látható a gerincvelőt komprimáló, a gerinccsatornát csaknem kitöltő Th. XII. meszes porckorongsérv. Az alsó sorban látható a CT-képeken a Th. XII – L. I. meszes porckorongsérv eltávolítása utáni állapot. A meszes osteophyta is elfúrásra került, a Th. XII. és L. I. csigolyák hátulsó részében minimális csonthiány ábrázolódik. Az axiális képen (alsó sor) látható a Th. XII. csigolya mellett a retroperitoneumban a vese a bal oldalon, illetve a borda mellett egészen vékony csíkként ábrázolódik a diaphragma és a gerinc mellé lenyúló tüdőállomány és pleurakettőzet (fehér nyíl)*

MINIMÁLISAN INVAZÍV EXTRAPLEURALIS THORACOTOMIA

Ebben a fejezetben az alábbi három esettel szeretnénk szemléltetni, hogy az általunk alkalmazott technikának (minálisan invazív, extrapleuralis thoracotomia) a hazánkban általánosan elterjedt thoracalis gerincfeltárások mellett van létjogosultsága. Az extrapleuralis feltárásnak köszönhetően a műtétek után pneumothoraxot egyik esetben sem tapaszaltunk.

1. thoracolumbalis junctióból meszes porckorongsérv eltávolítása, ami egyszerre retropleuralis és retroperitonealis feltárást is szükségessé tett a lokalizáció miatt, 2. thoracalis porckorongsérv eltávolítása, direkt elülső dekompresszióval, 3. spondylodiscitis miatt thoracalis corpectomia, direkt elülső dekompresszióval.

THORACOLUMBALIS JUNCTIÓBÓL MESZES PORCKORONGSÉRV ELTÁVOLÍTÁSA

A középkorú obes nőbetegnek évtizedek óta voltak derékfájdalmai. Az utóbbi hónapokban a beteg járástávolsága 5-10 méterre csökkent és terhelésre diffúzan a derékba, csípőkbe és az alsó végtagokba sugárzó fájdalmat tapasztalt. Fizikális vizsgálata során kétoldali Achilles-areflexián kívül objektív neurológiai eltérést nem találtunk.

Az elvégzett thoracalis és lumbalis gerinc-CT- és -MR-vizsgálat a Th. XII. – L. I. szegmentumban elhelyezkedő, igen nagyméretű, a gerinccsatornát kitöltő, kiszakadt, részben meszes porckorongsérvet mutatott, mely a conus-cauda átmenetet komprimálta **(4. ábra)**. Tekintettel a közel járásképtelen állapotra és a jelentős térfoglalást okozó Th. XII. porckorong sérvesedésére, annak műtéti kezelését javasoltuk.

Műtéti módszer

Miután a képerősítővel ellenőriztük a magasságot a Th. XII-es porckorongra centrálva, a porckorong vetülete fölött a XI-es bordával egyező irányban egy körülbelül 6 cm hosszú metszés ejtettünk, majd rácsmetszést alkalmazva jutottunk a XI-es borda felszínére. Az intercostalis izmokat átvágva a bordát körülbelül 6 cm hosszan reszekáltuk. Extrapleuralisan haladva jutottunk a gerinc bal oldalára, pleurasérülést nem tapasztaltunk. A feltárás során a diaphragmát is leválasztottuk a gerinc oldalsó felszínéről az extrapleuralis síkban, itt a retroperitoneumba jutottunk. A fali pleura alatt a belégzésekkel mozgó tüdőt a fali pleurával együtt lapocokkal medial és felfelé tartottuk el. A retroperitonealis zsírt a gerincről részlegesen leválasztott diaphrag-

mával együtt medial felé tartottuk el. Láthatóvá vált a m. psoas eredése az L. I. csigolya oldalsó felszínén. Ezt követően mikroszkóp alatt discectomiát végeztünk, továbbá a durazsák elülső felszínére direktben rálátva a meszes osteophytát fúró segítségével eltávolítottuk **(4. ábra)**. A műtétet követően a beteg járástávolsága az általános fizikai állapotának megfelelő szintre tért vissza, neurológiai tünete nem alakult ki, derék- és alsó végtagi fájdalmai jelentősen mérséklődtek.

THORACALIS PORCKORONGSÉRV ELTÁVOLÍTÁSA, DIREKT ELÜLSŐ DEKOMPRESSZIÓVAL

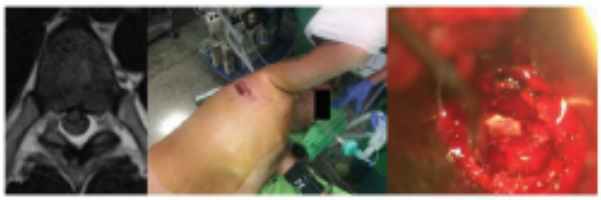
Az 1990-ben született férfi betegnél 2013-ban szeropozitív Devic-betegséget diagnosztizáltak. A betegnél jelentős látásromlás és súlyos paraparesis alakult ki, spasticus alsó végtagi tónusfokozódással. A betegnek új keletű panasza jelentkezett 2017 májusában: törzsizomzata meggyengült, enyhe törzsataxia alakult ki, illetve paraparesise jelentősen rosszabbodott. Háti gerinc-MR-vizsgálat készült, melyen Th. VI. porckorongsérv mutatkozott **(5. ábra)**.

Ideggyógyászati vélemény szerint a beteg állapotrosszabbodásában a háti porckorongsérv kóroki szerepe nem volt kizárható. Így a porckorongsérv eltávolítása mellett döntöttünk, azért, hogy a beteg járóképességét megőrizzük, illetve a törzsataxiát esetleg csökkentsük.

A beteget intratrachealis narkózisban, oldalfektetésben helyeztük el a műtőasztalon, a beteg felkarját a feje felé közelítettük azért, hogy az axillaris árok felnyíljon **(5. ábra)**.

Műtéti módszer

Miután a képerősítővel ellenőriztük a magasságot, a Th. VI–VII. porckorongra centrálva a VI-os bordával párhuzamosan egy ferdén lefelé futó, körülbelül 8 cm hosszú metszést ejtettünk, majd rácsmetszést alkalmazva jutottunk a VI-os borda felszínére.



5. ábra. *A képen bal oldalon a Th. VI. porckorongsérv ábrázolódik, mely a myelont jelentősen komprimálja. A középső képen a beteg fektetése látszik. A jobb kar felkötve, kipárnázva látható, hogy az axillaris árok alatti rész hozzáférhető legyen. A műtét után látható a zárt műtéti seb, illetve a bordadarab, mely eltávolításra került a műtéti feltáráshoz. Jobb szélső képen mikroszkóp alatt látható a durazsák elülső felszíne a porckorongsérv eltávolítása után*

Mindvégig gondosan ügyelve a pleura parietalisra, a bordát körülbelül 6 cm hosszan reszekáltuk.

Ezt követően extrapleuralisan a gerinc oldalsó felszínére jutottunk, oly módon, hogy a fali pleurát aprólékosan, tompán leválasztottuk a mellkasfal belső oldaláról, illetve a gerinc oldalsó felszínéről. A tüdőt a fali pleurával együtt előrefelé tartottuk el. Mikroszkóp alatt a Th. VI. és Th. VII. csigolyatestekben dorsalisan fúróval üreget képeztünk, majd a porckorong dorsalis része került eltávolításra, csak a csonthiánynak megfelelő szakaszon. A porckorongsérvet ezt követően a csigolyatestekben dorsalisan kialakított üregbe tudtuk billenteni és eltávolítani. A porckorongsérv eltávolítása után a dura teljes ventralis felszínére ráláttunk, meggyőződve arról, hogy ventralisan további kompresszió nem áll fenn **(5. ábra)**.

Valsalva-manővert alkalmazva a tüdő a fali pleurával együtt kitágult, majd rétegesen sebet zártunk. A műtét utáni közvetlen CT-vizsgálat pneumothoraxot nem mutatott. A felvételeken jól látható az anterolateralis megközelítésből eredő csonthiány **(6. ábra)**. A műtét után a beteg neurológiai állapota nem változott, sem az ataxiában, sem a paraparesisben nem sikerült változást elérni.

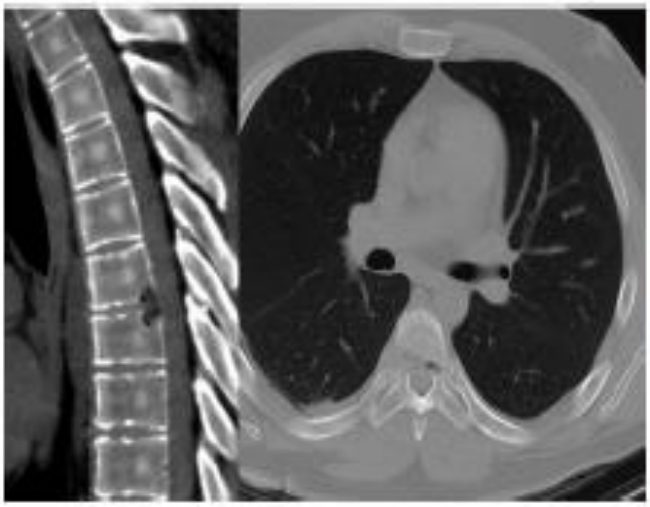
SPONDYLODISCITIS MIATT THORACALIS CORPECTOMIA, DIREKT ELÜLSŐ DEKOMPRESSZIÓVAL

A 64 éves férfi betegnél 2017 májusában kétoldali pneumonia igazolódott, majd nagy mennyiségű mellűri exsudatum miatt több lépésben mellkasi drenázs történt. Háti fájdalom és súlyos paraparesis miatt gerinc-CT- és -MR-vizsgálat készült. A felvételeken Th. X–XI. csigolyák spondylodiscitise és következményes myelonkompresszió igazolódott lokális kyphosissal. Tekintettel a súlyos paraparesisre, műtéti kezelés mellett döntöttünk.

Műtéti módszer

Miután képerősítővel ellenőriztük a magasságot, a Th. X. – Th. XI. csigolyákra centrálva, a X-es bordával párhuzamosan egy ferdén lefelé futó, körülbelül 8 cm hosszú metszést ejtettünk, majd rácsmetszést alkalmazva jutottunk a X-es borda felszínére **(7. ábra)**.

A feltárás lépései ezt követően megegyeztek az előbbi esetben ismertetett



6. ábra. *A műtét után hat órával készült kontroll-CT-felvételeket mutatja az ábra. A bal oldalon a porckorongsérv eltávolítása utáni csonthiány ábrázolódik a saggitalis irányú CT-képen. A jobb oldali axiális képen a csonthiányból megfigyelhető a minimálisan invazív, anterolateralis, retropleuralis feltárás hozzávetőleges tengelye. Látható, hogy a durazsák teljes elülső részét dekomprimáltuk, illetve jól megfigyelhető a tüdőrajzolat a teljes jobb oldali mellkasfélben, pneumothorax nem ábrázolódik*

7. ábra. *A felső képen a spondylodiscitisben érintett Th. X. és Th. XI. csigolyák vetülete látszik a mellkasfalra. A ferdén előre, lefelé futó vonal a tervezett bőrmetszést mutatja: a metszésvonal a Th. X-es csigolyatest hátulsó-felső sarkából a Th. XI-es csigolyatest elülső-alsó sarkába vezet, a középen futó X-es bordával párhuzamosan. Az alsó képpár bal oldalán intraoperatív kép látszik a feltárásról. A feltárás mélyén a Th. X. és Th. XI. corpectomia helyére befeszített Synex cage látható. A jobb oldalon a három darab feltáró lapátnak megfelelően az eltartott tüdő és fali pleura röntgenárnyékot adó vonala jól ábrázolódik*

műtéti lépésekkel. A fali pleurát sérülésmentesen tudtuk leválasztani mindkét csigolyatest oldalsó felszínéről.

A következő lépésben Th. X. és Th. XI. corpectomiát végeztünk és a gerincvelőt végig felszabadítottuk. A Th. X. és Th. XI. csigolyák helyére Synex lumbalis cage-et (Johnson and Johnson, Raynham, USA) feszítettünk be **(7. ábra)**, miközben a kyphoticus gerincszakaszra kézzel nyomást gyakoroltunk a kyphosis csökkentése céljából.

Valsalva-manővert alkalmazva a tüdő a fali pleurával együtt kitágult. A corpectomia helyére szívó drént helyeztünk, majd rétegesen sebet zártunk. Ugyanebben az altatásban a Th. VIII., Th. IX., Th. XII. és L. I. csigolyák transpedicularis percutan rögzítését is elvégeztük, összesen nyolc darab, egyenként 2 cm hosszú szúrt seben keresztül. A műtét utáni időszakban készült kontroll-CT-felvételeken pneumothorax nem ábrázolódott. A beavatkozást követően a beteg alsó végtagi izomereje javulást mutatott, minden izomcsoportban mozgás volt kivitelezhető. A beteget rehabilitációs osztályra emittáltuk, további antibiotikum-terápia mellett.

Megbeszélés

Napjainkban, hazánkban a thoracalis gerincszakasz sebészetében általános gyakorlat a costotransversectomia és a transthoracalis thoracotomia végzése. E módszerek mellett a minimálisan invazív extrapleuralis anterolateralis gerincfeltárás valódi alternatívát jelent. Az eljárás a nemzetközi irodalomban már korábban ismertetésre került, azonban eddig sem Magyarországon, sem külföldön nem terjedt el széles körben. Fontos megemlíteni, hogy az extrapleuralis, minimálisan invazív thoracalis feltárást minden esetben mellkassebész nélkül végeztük. A bemutatott technikát az idegsebészek könnyen el tudják sajátítani, ha jártasak a hagyományos costotransversectomiás és LECA-feltárásokban. Mellkassebész segítsége csak nem várt szövődmények esetében (például tüdősérülés, aortasérülés) szükséges, véleményünk szerint. A különböző thoracalis gerincmegközelítések jellemzőit az **1. táblázat** mutatja.

Az általunk alkalmazott minimálisan invazív extrapleuralis feltárás előzménye a McCormick által közölt megközelítés[2]. A bemutatott módszer azonban részleteiben már eltér a McCormick által közöltektől[8, 22]: az esetünkben alkalmazott bőrmet-

1. táblázat. *A thoracalis gerincszakasz megközelítésének típusai és a feltárások jellemzői*

	Rálátás a dura-felszínre	Kezelés intenzív osztályon	Pneumothorax	Mellkassebészeti jártasság	Speciális feltáró rendszer	Mobilizálás a műtét után	A metszés hossza
Costotransversectomia	dorsalis, lateralis	nincs	nincs	–	–	első napon	6–8 cm
Lateralis extracaviter feltárás (LECA)	dorsalis, lateralis, részben anterior	nincs	nincs	++	–	első napon	8–12 cm
Hagyományos transthoracalis feltárás	lateralis, anterior	van	van	+++	–	2–3 nap után	8–12 cm
Extrapleuralis MIS-feltárás	lateralis, anterior	nincs	nincs	+++	+++	első napon	6–8 cm

szés 6–8 cm-es, szemben a McCormick által közölt 12 cm-rel. A jóval kisebb behatolási kapu mellett a szöveteket kisebb kiterjedésben roncsoljuk, továbbá McCormick módszerével ellentétben nem szükséges dupla lumenű tubus alkalmazása, az adott tüdőfél deflációja szükségtelen.

A minimálisan invazív extrapleuralis anterolateralis gerincfeltárás úgy ötvözi a transthoracalis thoracotomia és a costotransversectomia előnyeit, hogy egyúttal alkalmazkodik a minimálisan invazív szemlélethez. A transthoracalis eljárásokhoz hasonlóan e módszerrel a durazsák/gerincvelő elülső dekompressziója direkt vizuális kontroll mellett végezhető. Az extrapleuralis feltárásnál, a costotransversectomiához hasonlóan, nem szükséges mellkascső behelyezése műtét után, hiszen mindvégig testüregen kívül maradunk a beavatkozás során. A transthoracalis megközelítéshez képest a retropleuralis feltárás átlagosan körülbelül 30 perccel hosszabb a fali pleura gondos leválasztása miatt. Az extrapleuralis feltárás véleményünk szerint gyorsabb felépülést, kisebb fájdalomszintet és kevesebb szövődményt eredményez, bár ezen állítások az alacsony esetszám miatt még nem igazolhatók statisztikailag. Bízunk benne, hogy ez a minimálisan invazív módszer elterjed hazánkban, tekintettel arra, hogy szinte minden, a thoracalis gerinc elülső felét érintő kórfolyamatban alkalmazható.

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The Alternative Approach to the Lumbosacral Segment: The Right-Sided Oblique Lumbar Interbody Fusion Compared with Anterior Lumbar Interbody Fusion

Viktor Szabó[1], Balázs Berta[1], Máté Nagy[1], Dominik Kulcsár[1], Gábor Perlaki[1-3], Attila Schwarcz[1]

BACKGROUND: Anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation (ALIF+D) is a well-described technique treating lumbosacral degenerative diseases. Mobilizing the common iliac arteries and veins during the ALIF+D approach may increase the risk of bleeding when the bifurcations are low. This study demonstrates that in such cases, the right-sided oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation (OLIF+D) offers a novel alternative to the ALIF+D approach.

METHODS: Twenty-one patients were operated on with the ALIF+D approach, and 20 patients were operated on using the right-sided OLIF+D technique. Computed tomography–based imaging and clinical data, such as patient-reported outcomes, were collected.

RESULTS: Both ALIF+D and OLIF+D surgeries elicited a statistically significant decrease ($P \leq 0.001$) between the preoperative and postoperative Oswestry disability index and the back and leg pain visual analog scale scores. A significant increase was observed in both techniques between preoperative and postoperative anterior segmental height, posterior segmental height, and segmental lordosis ($P \leq 0.001$). There were no statistically significant postoperative differences between patients operated by ALIF+D and patients operated by OLIF+D in the segmental lordosis angle ($P = 0.354$), anterior segmental height ($P = 0.297$), posterior segmental height ($P = 0.404$), Oswestry disability index ($P = 0.824$), or back and leg visual analog scale scores ($P = 0.682$ and $P = 0.979$, respectively). The OLIF+D group showed trend-like higher blood loss (198 ± 118 mL vs. 134 ± 77 mL; $P = 0.058$) and significantly longer surgical time (199 ± 47 vs. 169 ± 54 minutes; $P = 0.009$) compared to the ALIF+D group.

CONCLUSIONS: The right-sided lumbosacral OLIF+D approach is an alternative to the ALIF+D approach if the latter is hazardous due to vessel anatomy.

INTRODUCTION

Spinal fusion treatment of degenerative spine diseases aims to decompress nerve structures, reduce deformities, and restore stability.

There are 2 main decompression techniques in lumbosacral fusion surgery. The dorsal approaches (e.g., posterior lumbar interbody fusion, transforaminal lumbar interbody fusion) grant the direct decompression of nerve structures. In contrast, the anterior and oblique group (e.g., anterior lumbar interbody

Key words
- ALIF
- Anterior lumbar interbody fusion
- Lumbosacral
- Oblique lumbar interbody fusion
- Right-sided OLIF

Abbreviations and Acronyms
ALIF: Anterior lumbar interbody fusion
ALIF+D: Anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation
ASH: Anterior segmental height
CIA: Common iliac artery
CIV: Common iliac vein
CT: Computed tomography
ODI: Oswestry disability index
OLIF: Oblique lumbar interbody fusion
OLIF+D: Oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation
PSH: Posterior segmental height
VAS: Visual analog scale

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fusion [ALIF], oblique lumbar interbody fusion [OLIF], extreme lateral interbody fusion) allows indirect decompression. The benefits and risks of the various techniques are well described.[1]

Due to vascular anatomical characteristics, operating on the lumbosacral junction could be challenging from the anterior or oblique direction.[2,3] The lumbosacral disc can be approached between the common iliac artery (CIA) and common iliac vein (CIV) or lateral to them.

At least 4 techniques exist in the anterior and oblique fusion technique group to complete the abovementioned surgical goals for the lumbosacral junction.[4]

The best-known is the classic ALIF technique, when the patient is in Da Vinci position, and the approach is from the anterior direction via Pfannenstiel incision, reaching the disc between the blood vessels.[5]

The second option regarding cage insertion is also a "between the blood vessels" technique. However, the lateral decubitus position and the incision place suggest that this combines the ALIF and OLIF techniques.[6]

Further surgical options would be the lumbosacral extension of the OLIF technique lateral to the blood vessels from the right or left side.[7,8] The lateral lumbar interbody fusion, also known as extreme lateral interbody fusion or direct lateral interbody fusion method, is unsuitable for the lumbosacral junction.[9]

The main risk of anterior and oblique approaches to the spine is bleeding. The more obscured the lumbosacral disc is by the common iliac veins and arteries, the more the blood vessel must be mobilized and retracted to remove the degenerated disc and insert the cage, increasing the risk of bleeding and thrombosis.[10,11]

Magnetic resonance imaging can predict the possibilities of blood vessel mobilization. The classic ALIF method can be recommended if the bifurcations of the common iliac arteries and veins are located cranially from the fifth lumbar disc, and the anterior surface of the fifth lumbar disc is free or only minimal CIV mobilization is required. If the bifurcations are located low (Figure 1), or the left CIV does not have a fat plane or is attached to osteophytes, the mobilization of CIV is associated with a greater risk of bleeding.[12]

Examining further possible risks during the surgical approach, retrograde ejaculation can be one of the disadvantages of "between the vessels" techniques. However, with proper technique, this possibility is low and may be overestimated.[13]

Among the oblique approaches to the lumbosacral junction, the left-sided "lateral to blood vessels" OLIF technique is usually preferred.[14] In the absence of literature data, anecdotally, the right-sided "lateral to blood vessels" lumbosacral OLIF technique is considered dangerous and the least preferred technique.[7,15]

This single-center study aimed to demonstrate the feasibility and safety of the right-sided (left lateral decubitus position) lumbosacral OLIF approach compared with the classic ALIF technique based on clinical and radiological measures. When the vascular anatomy makes "between the blood vessels" techniques such as the ALIF approach hazardous, the lumbosacral "lateral to blood vessels" OLIF approach could be a safe and routinely applicable alternative.

METHODS

One experienced surgeon operated on every patient, and no access surgeon was involved in any case. All data were analyzed prospectively.

Patient Population

This study included only patients who received 1-segment lumbosacral surgery with supplementary dorsal percutaneous pedicle screw fixation.

The inclusion criteria were adult patients not improving after at least 3 months of nonsurgical treatment of the following lumbosacral degenerative diseases: postdiscectomy syndrome, degenerative disc disease, spondylolisthesis, and spondylolysis (Table 1). The exclusion criteria were patients suffering from neoplasia, infection, or trauma.

From February 2018 to February 2020, 21 patients underwent classic ALIF surgery (Johnson and Johnson, DePuy Synthes, and Synfix evolution cage) in the lumbosacral segment supplemented with dorsal percutaneous pedicle screw fixation.

Furthermore, between 2016 and 2022, 20 patients were operated on with the right-sided lumbosacral OLIF approach receiving supplementary dorsal percutaneous pedicle screw fixation.

At the time of surgery, the anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation (ALIF+D) patients were aged 47.2 ± 10.3 years (range: 18–63), while the oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation (OLIF+D) patients were aged 54.2 ± 10.5 years (range: 37–77).

The clinical follow-up time was 21.4 ± 21.2 (range: 7–84) months for the OLIF+D patients and 18.4 ± 8.9 (range: 8–40) months for the ALIF+D patients. Table 1 presents the demographic characteristics of both patient groups.

Outcome Assessment

Operative time, blood loss, implant failure, and wound healing problems were recorded. The neurological function of the lower extremity and the bladder and bowel functions were assessed.

Patient-reported outcomes included the visual analog scale (VAS) for low-back and leg pain and the Oswestry disability index (ODI) collected before the surgery and during the follow-up.

In addition, radiological measurements were made on the preoperative and follow-up computed tomography (CT) scans obtained in the same CT scanner at Pécs Diagnostic Center.

Segmental lordosis was measured in the median sagittal plane as the angle between the fifth lumbar vertebral body's upper endplate (L_5) and the sacral plateau (S_1). The anterior segmental height (ASH) was measured in the median sagittal plane as the distance between the fifth lumbar vertebral body's ventral cranial corner and the ventral corner of the sacral plateau. For the posterior segmental height (PSH), similar measurements were performed at the posterior margins.

The fusion was assessed on CT with bone window. The definition of fusion is controversial, and there is no widely accepted consensus on the measurement technique of spinal fusion.[16] Considering the concerns about the measurement techniques, the Bridwell fusion grade was used in the present study

(Table 2).[17] Postoperative flexion-extension radiographs were not performed routinely at our institution.

Cage subsidence was classified according to Marchi's 4-grade system: Grade 0 (0%–24% loss of postoperative disc height), Grade I (25%–49%), Grade II (50%–74%), and Grade III (75%–100%).[18]

Statistical Analyses

Statistical analyses were performed using SPSS, version 29.0 (IBM Corp., Armonk, NY, USA).

As parts of our variables were measured on an ordinal scale, and non-normality was indicated by significant Shapiro-Wilk test ($P \leq 0.05$) for many continuous variables or the differences between their preoperative and postoperative values, nonparametric statistical tests were applied.

The Wilcoxon signed-rank test was applied to compare preoperative ASH, PSH, segmental lordosis angle, ODI, back pain, and VAS back and VAS leg scores to postoperative ones. The Mann-Whitney U test was run to determine if there were differences in postoperative segmental lordosis angle, ASH, PSH, ODI, back and

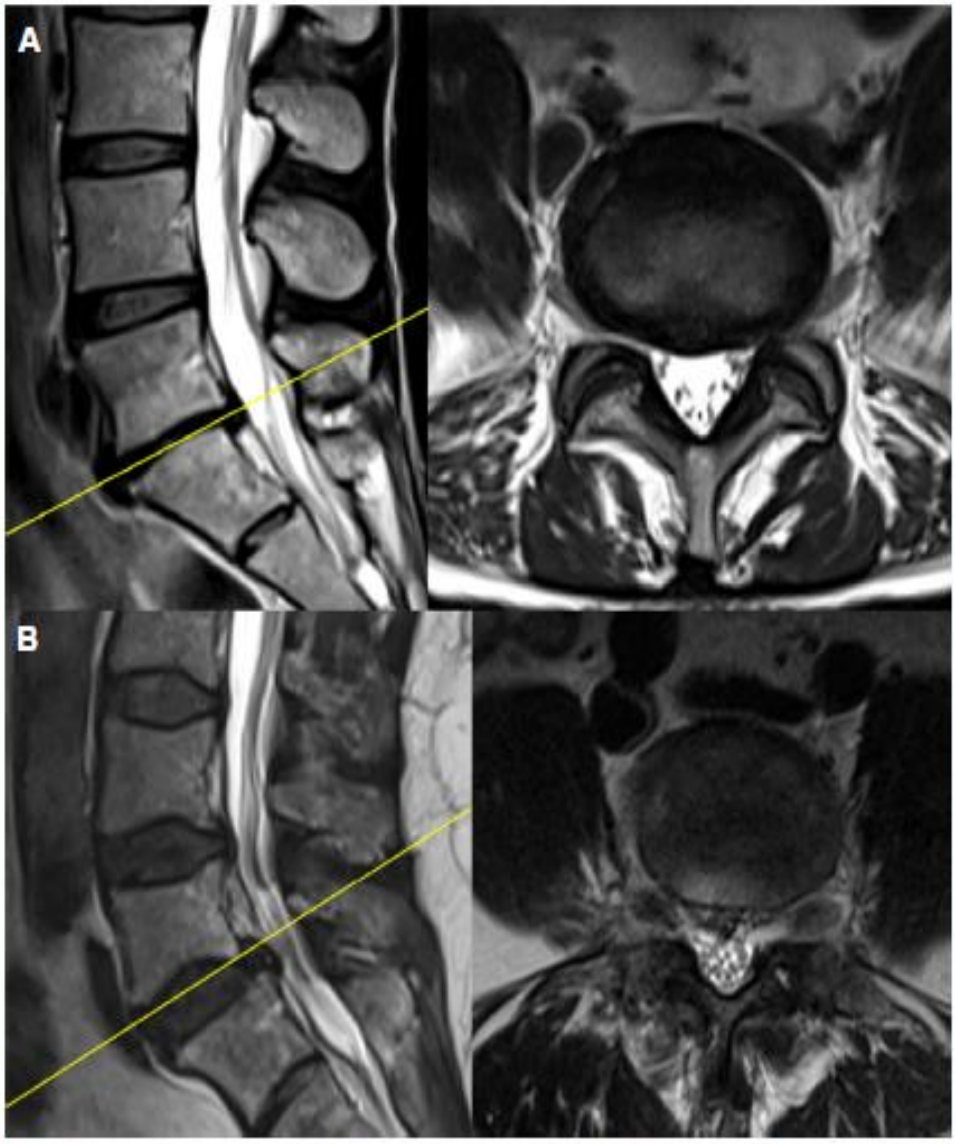

Figure 1. The vascular anatomical variations determine the choice between the anterior and oblique approach to the lumbosacral segment. (**A**) The picture represents an optimal patient for ALIF surgery. The common iliac vessels do not cover the fifth lumbar disc. Minimal or no vessel mobilization is necessary to implant the ALIF cage. (**B**) In the picture, mobilizing and retracting the left common iliac vein could be hazardous because the bifurcation is low. Retracting the right common iliac vein to the medial direction is less demanding during a right-sided OLIF+D surgery. ALIF, anterior lumbar interbody fusion; OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation.

Table 1. Demographic Characteristics of Patients Operated with Anterior or Right-Sided Oblique Lumbosacral Fusions with Dorsal Percutaneous Pedicle Screw Fixation: Anterior Lumbar Interbody Fusion with Dorsal Percutaneous Pedicle Screw Fixation and Oblique Lumbar Interbody Fusion with Dorsal Percutaneous Pedicle Screw Fixation, Respectively

	OLIF+D (n = 20)	ALIF+D (n = 21)
Gender (males/females)	9/11	4/17
Age at the time of surgery (years)	54.2 ± 10.5 [37–77]	47.2 ± 10.3 [18–63]
Follow-up duration (months)	21.4 ± 21.2 [7–84]	18.4 ± 8.9 [8–40]
Preoperative diagnosis		
Spondylolisthesis with spondylolysis	12	19
Degenerative spondylolisthesis (without spondylolysis)	6	1
Postdiscectomy syndrome	2	1

Age and follow-up duration are presented as mean ± SD (minimum-maximum).
OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; ALIF+D, anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation.

leg pain VAS scores, blood loss, or surgical time between patient groups operated by ALIF+D versus OLIF+D methods.

Right-Sided OLIF Surgical Technique

Patient Positioning. A cylindrical supportive cushion was applied below the armpit after carefully rolling the patient to a left lateral decubitus position. It is imperative to check that the armpit is not under compression by the edge of the table and that the patient's neck is in a natural position. When the patient is in the left lateral decubitus position, we usually lift both legs for a few seconds to adjust the pelvis's horizontal plane, which became unsettled during patient positioning. We typically bend the lower leg slightly in the knee and put a cushion between the knees.

Video

Video available at www.sciencedirect.com

Skin Marking. When the patient is in the proper lateral decubitus position, a C-arm is used to check that the patient is in the true anteroposterior and lateral position. Using a simple metal rod and a lateral fluoroscopy image, the projection of the fifth lumbar disc is marked on the skin with a pen (Figure 2).

Implants. A 5-cm long incision was made 2 fingers anteriorly from the iliac crest (Figure 2B). With a muscle-splitting technique, the muscle fiber of the abdominal muscle layers can be separated bluntly and parallel with the fiber, so damaging the muscle is unnecessary. Further blunt dissection with cotton wools in the retroperitoneal fat is necessary to prevent a peritoneal tear during the retroperitoneal approach. Following the curve of the peritoneum, the psoas muscle can be identified. Usually, the genitofemoral nerve is on the surface of the muscle. When the medial side of the psoas muscle was reached, a gentle retraction was made with the help of the Synframe retractor system (Synthes Spine, Paoli, Pennsylvania, United States), not forgetting that the ureter runs attached to the peritoneum (Video 1).

We can access the anterolateral part of the fifth lumbar disc between the psoas muscle and the right-sided CIV. However, the gentle retraction of the CIV is impossible without cutting the tethering iliolumbar and/or segmental veins. During an operation, ligating 1–3 segmental veins is usually necessary. Smaller veins can be electrocoagulated, but we use plastic clips for safety reasons for the thicker veins (Video 2). When every tethering vein was cut, the gentle retraction of the CIV and CIA should be performed without any resistance. If the retraction of the CIV is not easily performed, it suggests that some segmental veins remain hidden and must be found. As soon as the CIV no longer stands in our way, the OLIF cage can be implanted. During the cage implantation, the angle of the cage holder has to be aligned with the angle of the lumbosacral disc space to avoid endplate breach (Figure 3). Sanatmetal Emerald cage (Sanatmetal Ltd.) was used in every OLIF+D case. After the OLIF surgery, the patient was placed into a prone position, and percutaneous lumbosacral pedicle screw fixation was performed.

Table 2. Bridwell Interbody Fusion Grading System[17]

Grade	Description
I	Fused with remodeling and trabeculae present
II	Graft intact, not fully remodeled and incorporated, but no lucency present
III	Graft intact, potential lucency present at top and bottom of graft
IV	Fusion absent with collapse/resorption of graft

RESULTS

None of the patients had severe neurological symptoms before or after surgery, and no implant failures and wound-healing problems, such as deep infection, were observed. If we compare the postoperative data of the ALIF+D and OLIF+D groups, there were no statistically significant differences between the segmental lordosis angle ($P = 0.354$), ASH ($P = 0.297$), PSH ($P = 0.404$), ODI ($P = 0.824$), or the back and leg pain VAS scores ($P = 0.682$ and $P = 0.979$, respectively). However, the blood loss was higher

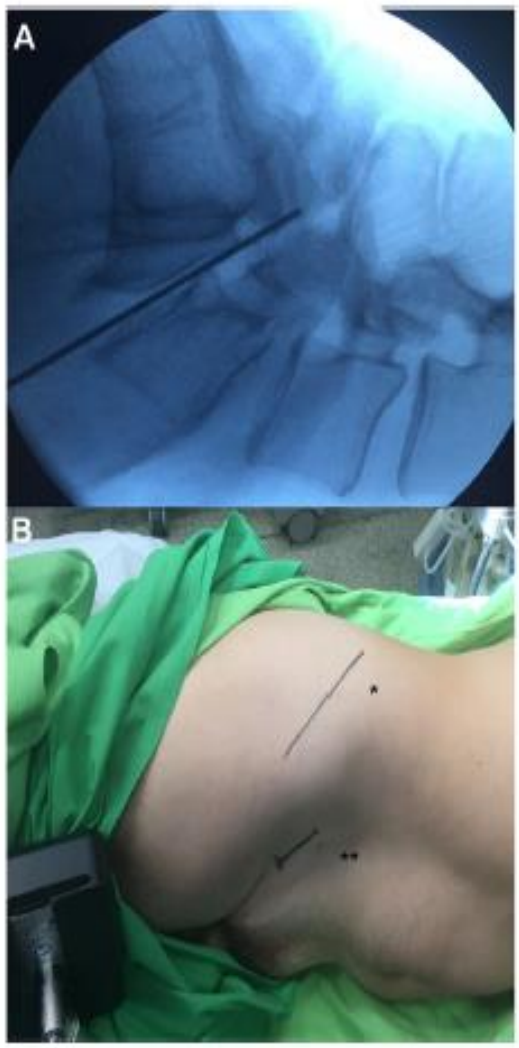

Figure 2 Preoperative skin marking for the right-sided OLIF+D surgery. (**A**) With the aid of the lateral fluoroscopy, the projection (*) of the fifth lumbar vertebra is marked on the skin, and (**B**) the plan (**) of the incision is also marked 2 fingers anteriorly from the right iliac crest. OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation.

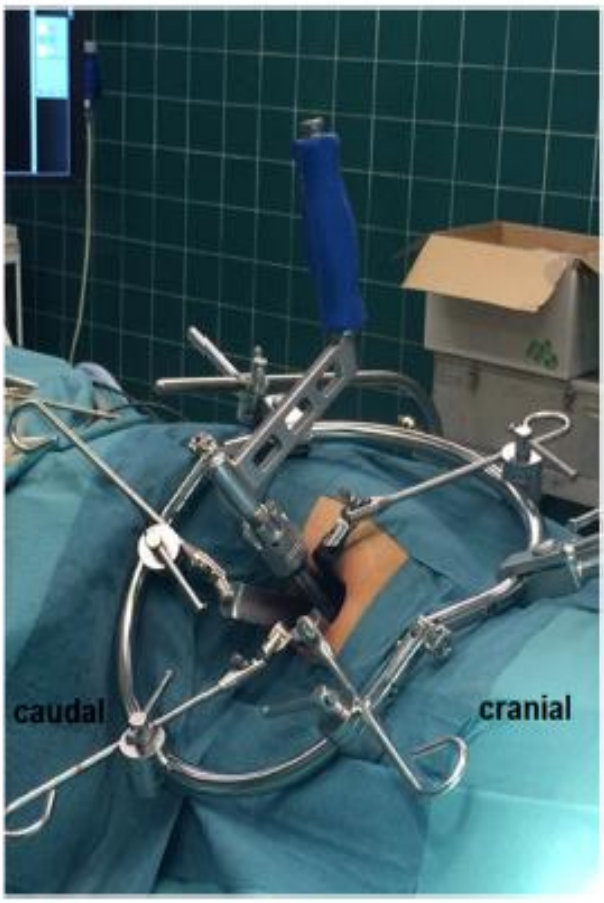

Figure 1 The cage insertion during the right-sided OLIF+D surgery. An important detail is that the blue hilted cage holder's angle, defined by the angle of the lumbosacral disc space, is similar to that of a patient operated on with ALIF+D but differs from that of the OLIF+D performed in the upper segments. The wound can be found 2 fingers anteriorly to the right iliac crest. OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; ALIF+D, anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation.

($P = 0.058$), and the surgical time was significantly longer ($P = 0.009$) in the OLIF+D group compared to those operated by the ALIF+D technique. Both surgical times include the dorsal percutaneous pedicle screw fixation with repositioning to the prone position (Table 3).

The only complication was experienced in our very first right-sided lumbosacral OLIF+D patient operated in 2016: the right CIV was injured, and the blood loss was 600 mL. The injury was treated with sutures without the help of a vascular surgeon.

Comparing the preoperative and postoperative data, the vertebrae's height gain ($P < 0.001$) and the segmental lordosis gain ($P < 0.001$) were significant in both the right-sided lumbosacral OLIF+D group and the ALIF+D group. Both techniques elicited a statistically significant decrease in the preoperative and postoperative ODI, VAS back, and VAS leg scores ($P < 0.001$ for all) (Table 4).

Subsidence was not observed in 19 right-sided lumbosacral OLIF+D patients; only 1 showed Grade I subsidence with Grade III on Bridwell's fusion grade (Table 2). Three patients showed Grade II fusion, and 16 resulted in Grade I fusion. In the ALIF+D group, 20 patients did not develop subsidence during the follow-up period, and only 1 patient showed subsidence, which was less than 25%. In this case, a Grade II fusion was formed. Two additional ALIF+D patients showed Grade II fusion, and 18 resulted in Grade I fusion (Figure 4).

DISCUSSION

Pros and Cons of ALIF+D and Right-Sided OLIF+D Approaches

The ALIF and OLIF approaches offer better variability in the size and lordosis of the cage compared to the dorsal approaches.[19] This is consistent with our article suggesting that the ALIF+D

Table 3. Comparison of Surgical Time, Intraoperative Blood Loss, and Postoperative Follow-Up Measures Between Patients Operated with Anterior and Right-Sided Oblique Lumbosacral Fusions with Dorsal Percutaneous Pedicle Screw Fixation

	OLIF+D (n = 20)	ALIF+D (n = 21)	P Value*
†VAS back	2.7 ± 2.4 [0–8]	3.2 ± 2.9 [0–9]	$P = 0.682$
†VAS leg	2.6 ± 2.4 [0–7]	2.9 ± 3.1 [0–10]	$P = 0.979$
†ODI	22.0 ± 22.1 [0–71]	21.6 ± 17.5 [1–56]	$P = 0.824$
†ASH (mm)	41.0 ± 3.7 [34.2–50.0]	39.8 ± 3.5 [34.5–50.0]	$P = 0.297$
†PSH (mm)	29.9 ± 3.5 [22.9–36.8]	28.8 ± 3.8 [21.7–37.0]	$P = 0.404$
†Segmental lordosis (degree)	21.3 ± 4.3 [11.8–28.4]	24.4 ± 7.3 [14.9–37.1]	$P = 0.354$
Blood loss (mL)	197.8 ± 118.5 [50–600]	133.8 ± 77.4 [40–280]	$P = 0.058$
Duration of surgery (minutes)	199.0 ± 47.0 [135–360]	169.0 ± 53.5 [105–300]	**$P = 0.009$**

Values are presented as mean ± SD (minimum-maximum).
P values < 0.05 are shown in bold.
OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; ALIF+D, anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; VAS, visual analog scale; ODI, Oswestry disability index; ASH, anterior segmental height; PSH, posterior segmental height.
*Mann-Whitney U test.
†Follow-up postoperative measures.

approach resulted in a slightly higher average postoperative lordosis value than the OLIF+D approach.

Furthermore, the larger footprint due to larger cages provided by OLIF and ALIF approaches reduces the chance of cage subsidence.[20] In this study, each group had only 1 subsidence with no clinical relevance. Both methods result in high bony fusion rates,[21] consistent with our research.

In our study, the average operation time of the ALIF+D was slightly shorter, which is explained by the patient selection based on vascular anatomy. The bifurcation of the CIVs did not cover the

Table 4. Comparison Between the Preoperative and Postoperative Clinical and Radiological Data in Patients Operated with Anterior or Right-Sided Oblique Lumbosacral Fusions with Dorsal Percutaneous Pedicle Screw Fixation

	Preoperative Value	Postoperative Value	P Value*
OLIF+D (n = 20)			
VAS back	8.1 ± 2.2 [0–10]	2.7 ± 2.4 [0–8]	**$P < 0.001$**
VAS leg	7. 9± 2.3 [1–10]	2.6 ± 2.4 [0–7]	**$P < 0.001$**
ODI	54.5 ± 22.7 [13–86]	22.0 ± 22.1 [0–71]	**$P < 0.001$**
ASH (mm)	36.7 ± 4.9 [25.4–44.3]	41.0 ± 3.7 [34.2–50.0]	**$P < 0.001$**
PSH (mm)	27.0 ± 3.0 [23.1–33.4]	29.9 ± 3.5 [22.9–36.8]	**$P = 0.001$**
Segmental lordosis (degree)	16.2 ± 6.0 [4.9–25.7]	21.3 ± 4.3 [11.8–28.4]	**$P < 0.001$**
ALIF+D (n = 21)			
VAS back	7.2± 2.7 [0–10]	3.2 ± 2.9 [0–9]	**$P < 0.001$**
VAS leg	7.4 ± 2.6 [0–10]	2.9 ± 3.1 [0–10]	**$P < 0.001$**
ODI	40.7 ± 15.0 [14–84]	21.6 ± 17.5 [1–56]	**$P < 0.001$**
ASH (mm)	34.0 ± 4.3 [28.0–43.6]	39.8 ± 3.5 [34.5–50.0]	**$P < 0.001$**
PSH (mm)	25.8 ± 3.8 [18.2–32.9]	28.8 ± 3.8 [21.7–37.0]	**$P < 0.001$**
Segmental lordosis (degree)	16.1 ± 7.8 [6.1–28.3]	24.4 ± 7.3 [14.9–37.1]	**$P < 0.001$**

Values are presented as mean ± SD (minimum-maximum).
P values < 0.05 are shown in bold.
OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; VAS, visual analog scale; ODI, Oswestry disability index; ASH, anterior segmental height; PSH, posterior segmental height; ALIF+D, anterior lumbar interbody fusion with dorsal percutaneous pedicle screw fixation.
*Wilcoxon signed-rank test.

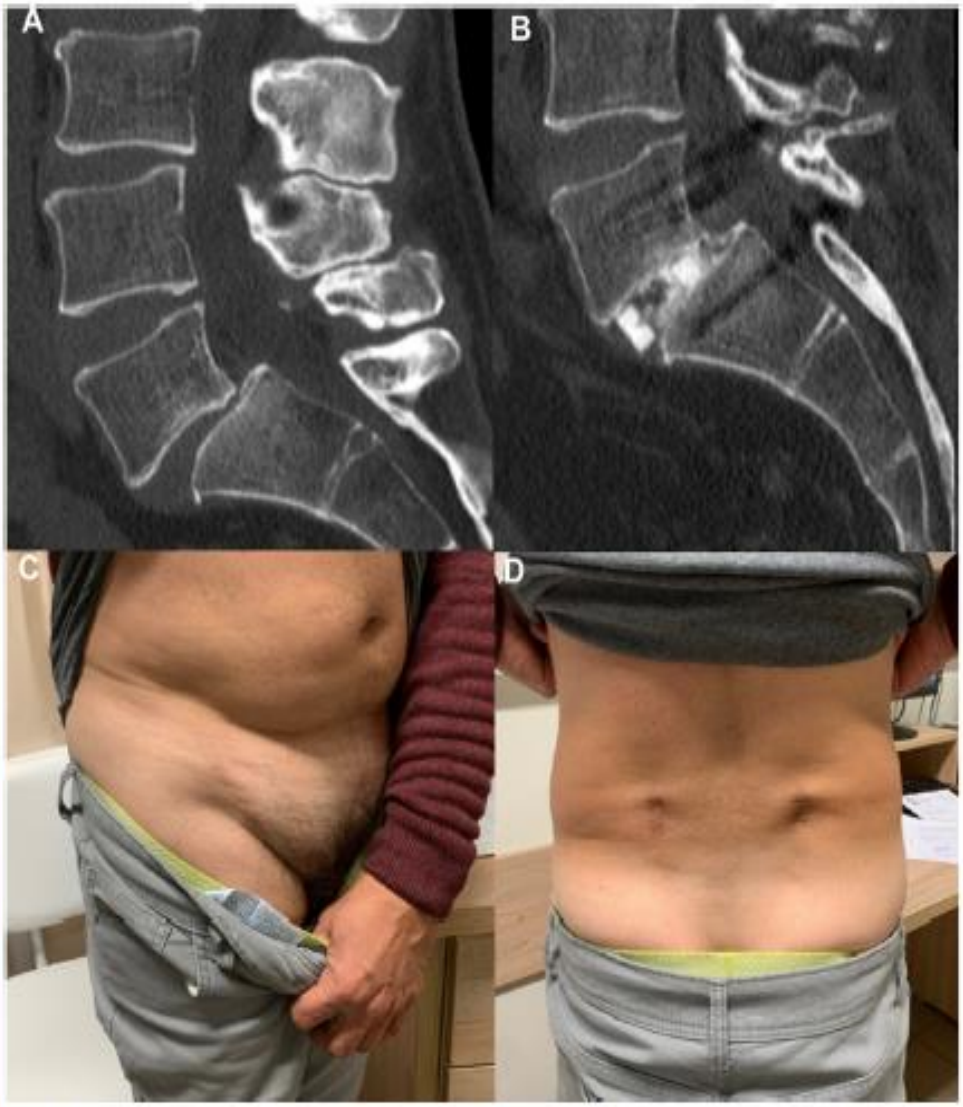

Figure 4. The results of the right-sided lumbosacral OLIF+D. The CT images acquired (**A**) before and (**B**) after the lumbosacral right-sided OLIF+D surgery in a patient with lumbosacral anterolisthesis due to spondylolysis. (**C** and **D**) The patient's wounds can be seen in the lower row on the 3-month follow-up. OLIF+D, oblique lumbar interbody fusion with dorsal percutaneous pedicle screw fixation; CT, computed tomography.

fifth lumbar disc in the cases of the ALIF+D approach. Because of the necessity of vascular mobilization, the lumbosacral OLIF+D cases were slightly more time-demanding. Yet the retraction of the right CIV to the medial direction is technically less cumbersome during the right-sided OLIF+D approach than the retraction of the bifurcation of the CIVs during the ALIF+D approach. This could be advantageous if the surgeon is less experienced in the ALIF approach or has no vascular surgeon available but does not prefer the dorsal approach. The OLIF and ALIF approaches produce more favorable blood loss and surgical time results than dorsal approaches, such as transforaminal lumbar interbody fusion.[1,22] The necessity of vascular manipulation can also explain the association with slightly more blood loss of the OLIF+D approach in our study.

Differences Between the Left-Sided and the Right-Sided OLIF+D Approaches

The OLIF+D technique from the right side can be safely applied in the lumbosacral junction, considering the differences between the left and right sides regarding the lumbosacral blood vessel anatomy.[23] The left CIA covers the lateral part of the left CIV. The consequence is that the low-pressure CIV is wedged on the left side between the high-pressure CIA and the vertebra, so its cross-section is often flattened.

The flattened left CIV must be mobilized and retracted during the ALIF+D and left-sided lumbosacral OLIF+D surgery. The CIA covers the anterolateral half of the CIV. Due to the flattened caliber, the left-sided CIV often lies on top of the junctions of the smaller incoming veins, such as the venovertebral vein or Maeng's

vein, causing the entry points of the segmental iliolumbar veins and the median sacral vein are also mostly covered.[24]

The situation is different on the right side. Before the bifurcation, the right-sided CIV is placed on the lateral side of the right-sided CIA and is less squeezed between the vertebra and the right-sided CIA, which is why its cross-section is round.[25]

The right CIV shows a straighter course, indicating a more predictable, easier mobilization. The critical point in mobilization is handling the segmental veins tethering the CIV. On the right side, the iliolumbar segmental veins running to the CIV are straighter, longer, and of smaller caliber, making them easier to ligate than on the left.[7]

Therefore, the choice between the ALIF and OLIF methods depends on the given vascular situation, which requires a preoperative assessment and planning.[12]

Our research presents experience from a single center with a limited number of cases.

Further studies in larger cohorts of patients are needed to have more experience with the right-sided OLIF+D approach.

CONCLUSION

This is the first study to describe and present the early results of the right-sided OLIF+D compared with ALIF+D in the lumbosacral segment. When the ALIF+D is risky, the right-sided "lateral to vessel" lumbosacral OLIF+D technique can be an alternative, yielding similar clinical and radiological outcomes.

ETHICS APPROVAL

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments. This study had received institutional research ethics approval (KK/307–1/2020).

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Viktor Szabó: Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Balázs Berta:** Investigation, Data curation. **Máté Nagy:** Investigation. **Dominik Kulcsár:** Investigation. **Gábor Perlaki:** Software, Formal analysis, Data curation. **Attila Schwarcz:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition.

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Conflict of interest statement: Attila Schwarcz participated in developing the Emerald OLIF cage produced by Sanatmetal Ltd. The rest of the authors declare no conflict of interest.

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