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EDITORIAL

Dear Colleagues,

Once again, it is my privilege to be publishing this, the 4th issue, of our professional journal this year. As you have come to expect, it includes several clinical research studies and review articles. I hope that each of you will take the time to read this issue thoroughly and incorporate anything you find useful into your practice.

In this issue, there are four clinical research and two review articles. The first study is a study concerning the "The Results and Complications of Interlaminar Endoscopic Approach for Lumbar Disc Herniation: An Overview of a Single-Surgeon Experience". The second is a research study entitled "Biomechanical Evaluation of Interspinous Device, Midfix in Destabilized Spine". In the third, one can read a retrospective clinical study entitled, "Retrospective Review of Spinopelvic Parameters in Patients Who Had Surgery for Lumbar Disc Hernia: Cross-Sectional Case Study". The fourth article is a retrospective study, "Wide resection in sacral osteoblastoma: case series". The authors of the fifth study wrote a review about "A Review of the Sinuvertebral Nerve in Discogenic Pain: Its Effects on Diagnosis and Management". The sixth study is a review about "Artificial Intelligence-Powered Spine Surgery: A Systematic Review of Current Trends and Future Prospects".

I hope you found this issue stimulating and informative. I do this in an effort to keep all of us on the cutting edge of the latest research and developments. My mission is, and has always been, to keep all of us on top of the most cutting-edge research in our field.

With kindest regards,

Editor in Chief

Metin Özalay, M.D.

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THE RESULTS AND COMPLICATIONS OF INTERLAMINAR ENDOSCOPIC APPROACH FOR LUMBAR DISC HERNIATION: AN OVERVIEW OF A SINGLE-SURGEON EXPERIENCE

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ABSTRACT

Objective: Interlaminar endoscopic approach has become a main operative option for lumbar disc herniations over the past decade. This method stands out for not only successful pain management but also for low complication rate, as shown in many studies. We aimed to present the results of a single senior surgeon with long-term follow-up.

Materials and Methods: The interlaminar approach was executed to 142 patients with lumbar disc herniation. In total, 151 disc herniations were performed. Motor deficit and intractable radicular pain were considered indication for interlaminar endoscopic lumbar discectomy (IELD), similar to open microdiscectomy. Cauda equina syndrome and vertebral instability deemed as contraindications.

Results: All patients had severe radicular pain. One hundred and thirty-two patients (92.9%) exhibited positive nerve stretch results, and 67 (47.2%) patients had motor deficit. Ten patients had a history of prior lumbar surgery. L4-L5 (33.1%) and L5-S1 levels (59.2%) were the most frequently operated levels. Nine patients (6.3%) underwent IELD for multiple level. Complications were noted in six patients (4.2%) during hospitalization. Dural tear occured in four patients (2.8%) and motor deficit was observed in one patient (0.7%). No repair surgery was required for dural tear. The mean follow-up duration was 9.1 years. Nine patients (6.3%) had recurrent disc herniation. The mean duration of recurrence was 20.9 months, and 77.8% of recurrences occurred in the first year. One patient underwent posterior stabilization 1 year after the last surgery. No infection or spondylodiscitis was experienced in our cases.

Conclusion: The results of a single experienced senior surgeon indicated that IELD was a highly safe method. This method is on course to become a common method for treating many lumbar spine disorders as technological advancements in endoscopic tools and the increase in patient experience.

Keywords: Endoscopic discectomy, interlaminar endoscopy, lumbar disc herniation

INTRODUCTION

A fully endoscopic approach has become the method preferred by many surgeons for lumbar degenerative diseases recently. The interlaminar and transforaminal approaches constitute the main pathways towards spinal canal and intervertebral foramen. In 2005, Ruetten(1) first described the interlaminar technique for lumbar discectomy. A stab incision, minimal muscle retraction, limited bone removal, unnecessity of significant neural manipulation, minimal loss of blood, shorter time for operation and, as a result, early return to daily work makes the endoscopic techniques more desirable to perform(2,3). Its indications were expanded as the endoscopic tools were advanced and the convenience of the method came out by many studies.

The endoscopes with narrower diameter and working canula would let the surgeon for lumbar discectomy unless the herniation located out of the spinal canal in earlier years(4,5). Less injury rates of normal structures and avoiding bone resection to get through the interlaminar space are the advantages of these endoscopes. On the other hand, widening the diameter and working canula in endoscopes provided broader manipulation by efficient bony work and better visual resolution. Paracentral or foraminal lumbar disc herniations with or without migration, central canal stenosis and unilaterally or bilaterally lateral recess stenosis can be performed with interlaminar endoscopic approach in any level of lumbar vertebra in cases with the absence of significant instability(6). Such advances in technology and increased surgical experience made spinal surgeons execute this technique more frequently.

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In addition to the successful outcome of endoscopic surgery in pain management, the complication rates make this approach to be considered a safe method. In this study, we present a single-surgeon experience using the interlaminar endoscopic approach, detailing the results from 142 patients. We describe the indications and surgical techniques employed, as well as a comparison of complications with existing literature.

MATERIALS AND METHODS

Interlaminar endoscopic lumbar discectomy (IELD) was performed on 142 patients using a uniportal technique. Nine patients had multilevel disc herniation and a total of 151 disc herniations were operated. Of 142 patients, 78 patients were males, and 64 patients were females (Male/Female: 1.2). The mean age of the patients was 42.9±12.2 years, with the ages ranging from 17 to 79. Prior to surgery, neurological evaluations were conducted, and all patients underwent magnetic resonance imaging (MRI) of the lumbar region. The patients with motor deficit and/or intractable radicular pain were considered candidates for surgery, as in indications for open lumbar microdiscectomy (Figure 1). Cauda equina syndrome and vertebral instability were acknowledged as contraindication for IELD. All perioperative and postoperative complications were noted. In the absence of early complications, the patients were mobilized on the same day of operation and discharged the following day.

Surgical Technique

The surgical technique described by Ruetten et al.[1,5] is fundamentally followed in all operations. The patients were fixed in the prone position on the operating table under general anesthesia. Biplanar fluoroscopic control was performed by positioning the C-arm beneath the operating table under sterile conditions. The incision site is first marked, and the skin and muscle fascia are simultaneously incised in a fashion medial to the midline of the targeted interlaminar space. Following a blunt insertion of the dilator with an outer diameter of 6.9 mm, a wider and beveled-opening surgical sheath (an outer diameter of 7.9 mm) was placed to the lateral edge of the interlaminar space under fluoroscopic guidance. Thereafter, a direct endoscopic view was provided through continuous irrigation during the surgery. Surrounding soft tissues were resected using cauterization and, the exposing ligamentum flavum was incised sufficiently to allow the manipulation the endoscope in the spinal canal. If the bony structures obstructed the access to the spinal canal, bone resection was performed using a burr or Kerrison rongeur. After visualizing the dura and nerve roots, the beveled opening of the surgical sheath was rotated to retract the nerve root to minimize neural damage. After cauterizing the epidural veins, discectomy was performed. In cases of caudally or cranially migrated disc herniations, the interlaminar approach provides a comfortable access along the entire level by allowing the endoscope to be maneuvered like a joystick after sufficient bony removal.

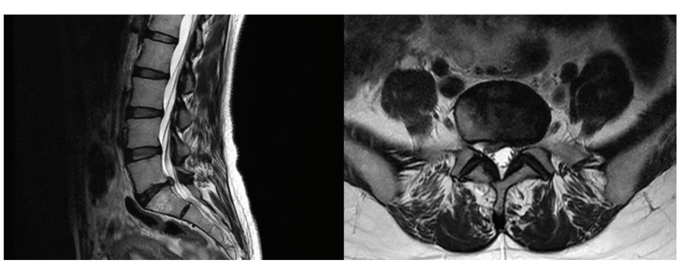

Figure 1. A right paracentral L5-S1 disc herniation caused severe right leg pain and motor deficit was operated with interlaminar endoscopic approach

Statistical Analysis

All variables in patient database were assessed with descriptive results obtained. All statistical analysis was conducted using SPSS v26.0 (IBM Corp., Armork, USA).

RESULTS

A total of 151 IELDs were executed in 142 patients. In preoperative evaluation, a positive nerve stretch test was positive in 132 patients (92.9%) with the Lasegue test positive in 130 (91.5%) and the femoral stretch test positive in two (1.4%). Sixty-seven patients (47.2%) had motor deficit, and 36 patients (25.4%) had hypoesthesia in the relevant dermatome. Additionally, 3 patients (2.1%) presented neurogenic claudication due to concomitant spinal stenosis secondary to large disc fragments. A history of previous lumbar surgery was noted in 10 patients, of whom five had undergone microdiscectomy and five had received endoscopic discectomy. The majority of the procedures were performed at the L4-L5 and L5-S1 levels (33.1% and 59.2% respectively). Also, one patient had an operation for D12-L1 level and one for L1-L2 level (Table 1). Nine patients (6.3%) underwent IELD for multiple levels. Of 9 patients, one underwent IELD for single-level lumbar disc herniation and two-level spinal stenosis, while others for multiple-level lumbar disc herniation. Sixty-five patients were operated only on the right side (45.8%), 75 patients (52.8%) were only on the left side, and 2 patients were bilaterally operated on (1.4%). In 8 cases, additional ipsilateral foraminotomy and/or decompression was made to have optimal relief of neural structures.

A total of 6 patients (4.2%) had surgery-related complications. Dural tear occurred in 4 patients (2.8%) and motor deficit was encountered in 1 patient (0.7%). One of the patients with dural tear had accompanying spinal stenosis and underwent decompression. None of the patient with dural tear developed closed or open cerebrospinal fluid (CSF) fistula requiring surgical repair. In another patient, pain did not improve after surgical intervention. A lumbar MRI revealed incomplete disc removal, and the patient underwent additional surgery for discectomy during the hospitalization. The mean follow-up duration for the 142 patients is 9.1 years (range, 2-12 years).

Table 1. Demographics and clinical features

	Total		L4-L5		L5-S1		Upper lumbar		Multiple	
	n	%	n	%	n	%	n	%	n	%
Number of patients	142	100	47	33.1	84	59.2	2	1.4	9	6.3
Age	42.9		48.55		40.3		53.5		37.6	
Male/female	78/64	1.2	26/21	1.2	48/36	1.3	0/2	-	4/5	0.8
Side										
Right	65	45.8	26	55.3	33	39.3	0	0	6	66.7
Left	75	52.8	21	44.7	51	60.7	2	100	1	11.1
Both	2	1.4	0	0	0	0	0	0	2	22.2
Neurological findings										
Motor deficit	67	47.2	23	48.9	39	46.4	0	0	5	55.5
Sensorial deficit	36	25.4	9	19.2	25	29.8	1	50	1	11.1
Nerve stretch test	132	92.9	44	93.6	78	92.9	1	50	9	100
Claudication	3	2.1	1	2.1	2	2.4	0	0	0	0
Complication										
Dural tear	4	2.8	3	6.4	1	1.2	0	0	0	0
Recurrent	9	6.3	2	4.3	7	8.3	0	0	0	0
Incomplete removal	1	0.7	1	2.1	0	0	0	0	0	0
De novo motor deficit	1	0.7	1	2.1	0	0	0	0	0	0
Infection	0	0	0	0	0	0	0	0	0	0
Previous lumbar surgery	11	7.8	4	8.5	7	8.3	0	0	0	0

During the follow-up, 9 patients (6.3%) had recurrence at the same lumbar level, and another surgical intervention was recommmended. The recurrences occurred in a mean interval of 20.9 months (15 days-7 years). Seventy-seven point eight percent of the recurrences occurred in the first year (4.9%), and the mean duration of recurrence is 6.4 months when excluding the recurrences that occur after one year. Eight patients with recurrence had undergone either microscopic or endoscopic discectomy once during the follow-up. One patient who initially had IELD surgery first operated for recurrent disc herniation with IELD technique, but the patient underwent another surgery for posterior stabilization one year after the last operation. No infections or secondary spondylodiscitis were reported among our cases. When examining the recurrence timing of the surgeon, 6 patients (66.6%) were included in the first half of the patient group during the initial three years. Also, the same difference was observed in the distribution of surgical complications over the years. Four surgical complications (66.6%) occurred in the initial three years, including the incomplete disc removal.

DISCUSSION

Recently, IELD is getting preferable among the spine surgeons. Many neurosurgery and orthopaedic surgery clinics have been executing endoscopic discectomy techniques more frequently rather than discectomy under operating microscope. Moreover, endoscopic spine surgery is advancing to be recognized the primary method for the disc surgery[7]. In 2016, Ruan et al.[8] estimated that endoscopic and microscopic techniques achieve similar success and complication rates excepting the shorter operating time and hospital stay on behalf of endoscopic technique. A later meta-analysis by Li et al.[9] presents that endoscopic discectomy has benefits to minimize intraoperative incidents. Also, they mentioned that both techniques yield comparable outcomes regarding success and recurrence rates. Another study of Barber et al.[10] highlighted the advantages of endoscopic discectomy, including perioperative blood loss, quicker return-to-work times, postoperative visual analogue scale and Oswestry disability index scores, and specific biomarkers. However, they also commented that most studies included in their meta-analysis were retrospective and a high risk of bias should be considered[10]. It should be remembered that the success of endoscopic technique is yet considered to rely on proper patient selection and the execution of precise surgical method [11].

As a complication of discectomy, dural tear might result in poor outcome such as spinal headache, CSF fistula, pseudomeningocele, meningitis or epidural abscesses which may necessitate an additional surgical intervention. In open microdiscectomy, the prevalence of dural tear varies from 1% to 17%[12]. In a study by Sencer et al.[13], the rate of dural tear after percutaneous IELD was presented as 3.6% and, they stated that one of the 6 patients needed surgery for open CSF fistula. Solimon mentioned a rate of 6% for dural tears after interlaminar endoscopic approach. But their indication for interlaminar endoscopic approach is spinal stenosis and the difference of pathological entity and the need of more surgical manipulation may ease to occur dural tear[14]. For unilateral biportal endoscopic approach (UBE) to lumbar disc herniations, he reported a rate of 4.7% for dural tears in another study[15] and Kim et al.[16] reported a rate of 3.3%. For dural tear, the rate in endoscopic lumbar approaches might be mentioned as 2.7% (range, 0-8.6%) according to another study[17]. On the other hand, Lewandrowski et al.[18] exhibited a total rate of dural tear as 1.07% for endoscopic lumbar surgery, with an extremely low CSF fistula rate of 0.025%. Gautschi et al.[19] mentioned that 79.4% of spine surgeons use artificial sealant patches or other glue products to repair dura without direct suturing. In our series, we encountered dural tear in four patients (2.8%). All dural injuries occurred during the manipulation of surgical sheath to retract the nerve root and three of four patients had caudally migrated disc herniation (Figure 2). None of these patients had a history of previous lumbar surgery. In our cases, a commercial fibrin glue product was used to seal the durotomy area, and the suturing was not required. No open or closed CSF fistula have been experienced after incidental durotomy.

The difficulties in manipulation of surgical sheath may also be a reason of transient or permanent motor deficit in addition to the dural tear. Despite the similarities of the procedure with microscopic technique, the surgeon can readily be disorientated in consequence of the misplacement of surgical sheath, especially with lack of experience. Both the traversing root and exiting root are at risk if the surgical sheath is positioned more medially or laterally than necessary[20]. Postoperative motor deficits mostly tend to be transient and occur less frequently than dural tears. In our series, we only encountered postoperative drop foot in one patient who underwent surgery for sequestrated and cranially migrated L4-L5 disc herniation (0.7%). In the literature, there are several studies to report motor deficit after endoscopic lumbar surgery with low rates. In a study on complications of both transforaminal and interlaminar endoscopy, the motor deficit occurred in a rate of 0.8% in the patients executed IELD[21]. And in another study, Choi et al.[22] mentioned a rate of 1.5% for neural injury in the learning curve period of UBE. Shriver et al.[23] reported a rate of 1.6% for new neurological deficit in percutaneous procedures, however, they found no statistically significant compared to microscopic discectomy, which had a rate of 3% for new neurological deficit. In a study focused on disc herniations of L4-L5 level, migrated or extruded disc herniations are identified as independent risk factors motor deficit and delayed recovery[24], indicating a higher likelihood of complications associated with retracting the nerve root in these cases. Although the optimal position of surgical sheath can be established after high-speed drill of lateral edge of interlaminar space, it must be noted that anatomical variations of roots may be occasionally encountered and pose challenges. The lumbosacral region (L4-S3) has the highest incidence of intradural and extradural variations including close spacing between the roots and extradural anastomoses[25]. In our case, the traversing root was found to be exiting dura at a higher position and leading the surgeon to approach the axilla of the traversing root via interlaminar route. To retract the traversing root medially and access the herniated disc, the bone resection was extended laterally to position the working sheath next to nerve shoulder. However, we believe that placing the working sheath laterally in a location with minimal space between the exiting and traversing root, due to a higher positioning of traversing root, resulted in inreased compression in addition to the pressure from the herniated disc material, until optimal decompression was achieved.

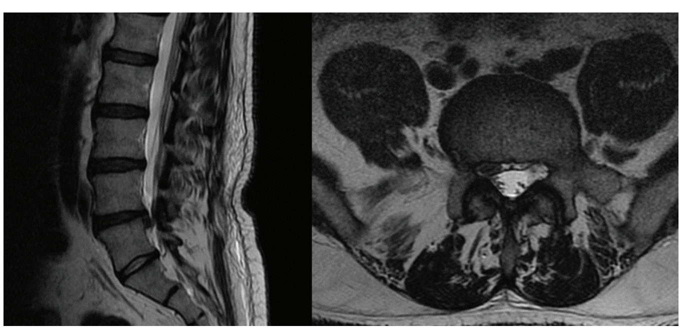

Figure 2. A sequestrated and caudally migrated L4-L5 disc herniation extending into the right lateral recess. Dural tear occurred during the surgery, but no CSF fistula observed or dural repair is needed in postoperative period
CSF: Cerebrospinal fluid

The recurrence of disc herniation after surgical intervention have been widely discussed and several risk factors have been mentioned yet. Cinotti et al.[26] and Suk et al.[27] indicated young age, male age, trauma history, and smoking as risk factors of recurrence. Moliterno et al.[28] stated that the patients with relatively low body mass indices tend to have higher recurrence rate, while Kim et al.[29] mentioned that the older age and higher body mass index were significantly associated with recurrence of disc herniation due to increased degeneration of disc. Diabetes also has been identified as a clinical and histopathological risk factor for recurrence with lower buoyant density of proteoglycans of the disc material[30]. A meta-analysis showed that the recurrences occur more frequently within the first 6 months after surgery[31]. Our series also presented that the early recurrences are more common, similar to the literature. Recurrence rates are vary in many studies, even those with the longer follow-up periods in the literature. Wu et al.[32] stated a recurrence rate of 8.2% within 30 months of follow-up. Kim and Park[33] showed a 10.3% recurrence rate after a mean follow-up duration of 19.5 months. In a prospective randomized controlled study of Ruetten et al.[34], a recurrence rate of 6.6% was reported with 24 months of follow-up. Various retrospective studies have documented very low or no recurrence rates through endoscopic interlaminar approach (0-1.4%)[35-37]. But Yin et al.[31] calculated the pooled recurrence rate as 4.2% for endoscopic interlaminar approach in their meta-analysis, with a follow-up duration ranging from 6 and 60 months. The early recurrence rate is 4.9% in our case series (Figure 3).

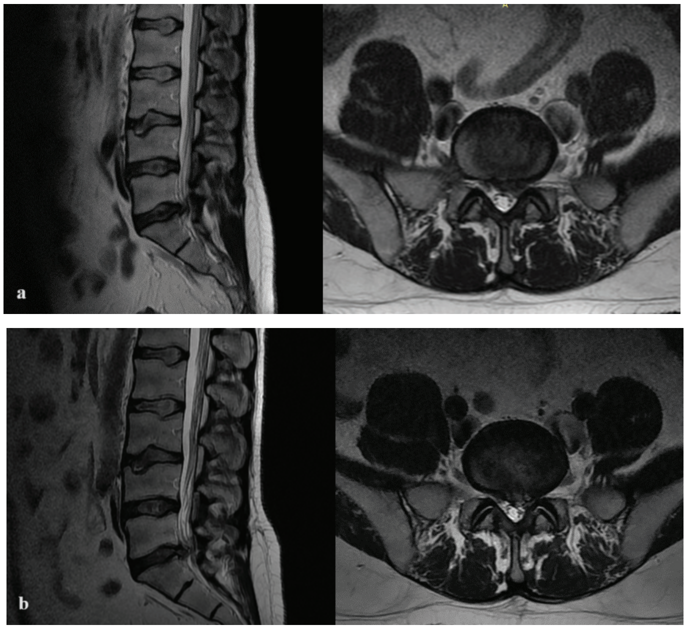

Figure 3. (a) A patient underwent IELD for left paracentral disc herniation in the level of L5-S1. (b) Six months later, the patient was operated for a recurrent disc herniation in the same region
IELD: Endoscopic lumbar discectomy

Compared to the literature, we have a longer mean follow-up period and the recurrence rate reached 6.3% after the mean period of 9 years. One of our patients who was operated for recurrent disc herniation required a stabilization surgery due to developing spondylolisthesis at his third year after the initial surgery. Also, one of our patients underwent additional intervention due to the failure of pain relief after the surgery and we defined the case as incomplete herniation removal instead of recurrence.

The studies addressing the learning curve for IELD is particularly limited compared to transforaminal approaches in the literature. A collective review for learning curve of all endoscopic spinal procedures mentioned that the majority of the studies indicated no influence of experience on complication and recurrence rates[38]. Similarly, the studies focusing specifically on IELD did not demonstrate an association between the increased experience and change in the rate of those[39,40]. In our series, we observed differences in complication and recurrence rates after the first half of the patients underwent surgery. While these results should be included in a larger meta-analysis for more robust evaluation, at least, it is worth noting that our series includes a larger number of patients compared to many other studies.

Infections following IELD have been rarely reported. In our series, we did not encounter any surgical site infection. Many studies mentioned no infection in their series including with the large number of cases[37,41,42]. Deep surgical site infection was presented in a study of Yorukoglu et al.[21] with a rate of 0.14%, in a study of Liu et al.[43] with a rate of 0.79% and in a study of Wang et al.[44] with a rate of 0.6%. Fukuhara et al.[45] suggested that the low postoperative infection rates after endoscopic lumbar surgery are attributed to the requirements of the surgical method such as small incision and continuous irrigation. It should be considered that the postoperative infection rates after microscopic lumbar discectomy are also reported to be below 1% in the literature[46,47]. A meta-analysis of 42 articles presented that superficial and deep surgical site infections do not show any significant difference between microscopic lumbar discectomy and endoscopic lumbar discectomy (2.1% for microdiscectomy vs. 0.5% for endoscopic discectomy)[23]. While we acknowledge that IELD is a very safe method for minimizing the risk of surgical site infection, we do not claim it to be superior to microscopic discectomy.

Study Limitations

This study examined a cohort of patients who underwent a specific surgical procedure performed by a single surgeon. Our aim was to present the complications while minimizing the effects of multiple surgeons and their differing approaches. Since all patients received the same treatment, a comparative analysis was unnecessary. We briefly noted the surgical success in terms of pain relief and did not provide a scale to compare preoperative and postoperative pain levels. Although this was not the primary focus of our study, the absence of a pain scale may be seen a limitation of our article. Also, we searched the literature to review the differences with UBE, however, the various inferences were limited in the literature, since UBE is a relatively recent technique in spinal surgery.

CONCLUSION

IELD is not only an effective method for achieving adequate disc removal, minimal tissue harm, earlier mobilization and shorter hospital stay but also a safe one with low complication rates. Because the spinal endoscopic procedures are not routinely executed worldwide and the procedures are not commonly a part of basic training of the neurosurgical surgeons, a higher complication rates may be encountered during the learning curve. Nonetheless, the results of a single experienced senior surgeon indicate that the safety of IELD is satisfactory and consistent with the literature. With the technological advances in the endoscopic tools and the increase in experience, the spinal endoscopic procedures have the potential to become common option for treating many lumbar spine disorders.

Footnote

Ethics Committee Approval: No ethics commitee approval has been sought since this observational study was conducted retrospectively.

Informed Consent: Retrospective study.

Authorship Contributions

Surgical and Medical Practices: M.İ., Concept: O.Ö., M.O.A., M.İ., Design: O.Ö., M.O.A., M.İ., Data Collection or Processing: O.Ö.,

M.O.A., M.İ., Analysis or Interpretation: O.Ö., M.O.A., Literature Search: O.Ö., Writing: O.Ö.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study received no financial support.

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BIOMECHANICAL EVALUATION OF INTERSPINOUS DEVICE, MIDFIX IN DESTABILIZED SPINE

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ABSTRACT

Objective: The purpose of this study was to evaluate the stability and loosening of the Midfix device under complex cyclic loading with the resection of interspinous and supraspinous ligaments.

Materials and Methods: A biomechanical study of motion analysis and cyclic loading on six fresh-frozen lamb spines was conducted. Specimens were divided into three groups: control, destabilized, and midfix groups. The excision of interspinous and supraspinous ligaments was performed in the destabilized and Midfix groups. Axial loads of 400 N were applied to the spine, and an increased moment of up to 8400 N-mm was generated through the axial movement to achieve the flexion-extension (FE) and right-left bending (LB) motions. During testing, the extensometer recorded the intervertebral displacement at decompression levels L4-5. According to the analysis, the value for which $p<0.05$ was considered statistically significant.

Results: Implantation of the ISD (Interspinous Device) to strengthen segment stabilization resulted in a significant decrease in the range of motion of 43.2% in extension, 57.8% in flexion, and 25.6% in LB, yet an increase in right bending by 25.6%. A comparison between the intact spine and Midfix groups revealed significant differences in the range of motion in FE and LB. However, there were no statistically significant differences in right bending.

Conclusion: The Midfix device stabilized the segments after resecting the interspinous and supraspinous ligaments. In addition, Midfix was more effective in flexion and extension than the other loading modes. Therefore, the lack of a stabilizing effect in bending should be carefully considered.

Keywords: Biomechanics, lumber spine, interspinous device, lamb

INTRODUCTION

Low back pain (LBP) stands as one of the most prevalent global health issues concerning musculoskeletal problems, presenting a considerable challenge to clinicians tasked with its management[1]. Based on the severity of the pain and the patient's condition, the treatment of LBP ranges from conservative to surgical[2]. Surgery is the treatment option that is employed following conservative treatment failure in LBP.

Depending on the condition causing the LBP, there are different surgical procedures, including decompression with or without arthrodesis, decompression arthrodesis with or without instrumentation, fusion with or without instrumentation, and non-fusion dynamic stabilization devices to treat spinal pathologies[3]. However, among these procedures, spinal fusion is the gold standard in treating degenerative spine diseases. Moreover, fusion without instrumentation often leads to the non-union of bone, which is called pseudoarthrosis. Many spinal implants, including cages, plates, screws, pedicle screws, rods, and wires, were designed to overcome this complication and to stabilize the fused spine.

Non-fusion procedures, such as dynamic stabilization, total disc arthroplasty, interspinous devices (ISDs), and less invasive systems have been developed as alternative treatment options for spine stabilization[2,4,5].

Minimally invasive spine surgery (MISS) involves performing small incisions. These procedures have advantages compared with conventional surgeries, including reduced blood loss, less damage to surrounding muscles, and reduced surgery time[6,7]. Technological improvements have led to the development of new MISS instruments that increase the stability of spine with less invasive surgical exposure. ISDs are dynamic stabilization systems that are implanted between spinous processes using minimally invasive techniques. The primary mechanism of

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ISDs is to decrease the load of facet joints and the distraction between adjacent spinous processes to block intervertebral extension at the level of application. They allow movement of the spine while providing stability[8,9]. Indications for the use of ISDs encompass various conditions including spinal stenosis, degenerative spondylolisthesis (grade 1), discogenic pain in low back, facet joint pathologies, lumbar disc herniation, and non-traumatic instability[9]. Different designs of ISDs are tailored to address specific needs, such as solely limiting extension or restricting both flexion and extension.

ISD use has only recently become widespread; therefore, few biomechanical and clinical studies have reported on the effectiveness of these devices[10,11]. Karahalios et al.[5] conducted a comparative analysis of the Aspen device alongside alternative devices, including its application when used alongside anterior lumbar interbody fusion (ALIF). Kaibara et al.[12] undertook a biomechanical investigation utilizing the

Aspen system in conjunction with transforaminal lumbar interbody fusion. Wang et al.[4] performed a biomechanical assessment of the CD-HORIZON-SPIRE fixation system, evaluating the stability of SPIRE with both uni-bilateral inserted pedicle screws in a destabilized spinal.

The Midfix (Huvexel, South Korea) ISD was designed to provide supplemental fixation and to support a minimally invasive surgical technique. Midfix is an all-in-one device consisting of two lateral plates with spikes and one vertical plate with a locking hole (Figure 1).

The Midfix device is implanted between the vertebral spinous processes and provides a fixation site toward the laminar and spinous processes coexisting with a bone grafting site (Figure 2). This device is made up of titanium that is biocompatible in the human body. Midfix is indicated in patients with degenerative spondylolisthesis, spinal instability, and recurrent disc herniation. In addition, it can be used with the adjunct of an upperinstrumented vertebra to pedicle screw fixation, especially in deformity correction.

The aim of this study is to evaluate the stability provided by the Midfix device under cyclic loading during flexion-extension (FE) and lateral bending in six fresh-frozen lamb lumbar segments without the posterior ligaments. We hypothesized that resection of the interspinous and supraspinous ligaments would not reduce the stability of the lumbar spinal segments instrumented with a Midfix ISD.

MATERIALS AND METHODS

This study was approved by the Dokuz Eylül University Non-Interventional Research Ethics (approval number: 2021/28-03, date: 13.10.2021), and was performed using standardized loading protocols[13]. As this study involved animal specimens, no patient informed consent was obtained.

Specimen Preparation

The number of specimens was determined based on a previously conducted study that analyzed the suitability of different animal specimens for pre-clinical implants[14,15]. Six fresh-frozen lamb spines (including L1 to L5 vertebrae) were used in this study. Each specimen was thawed 12 hours before

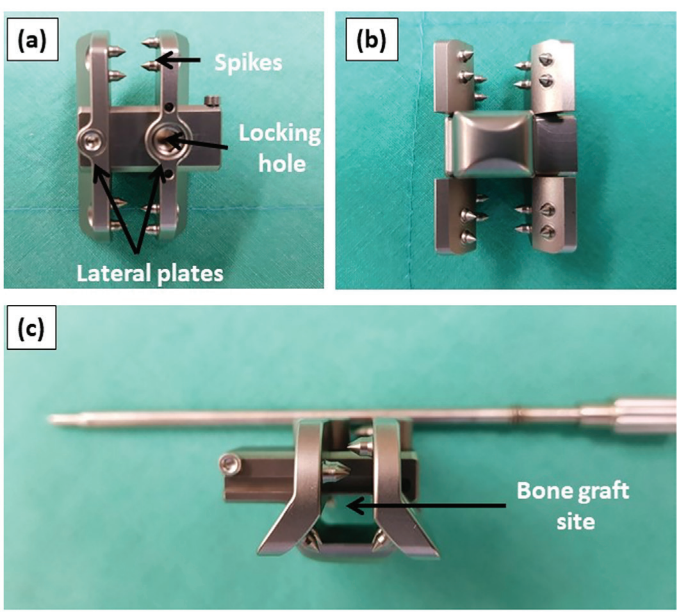

Figure 1. Midfix interspinous fusion device (a) posterior view (b) anterior view (c) superior view

Figure 2. Midfix interspinous fusion device placed in between spinous processes

testing to return it to normal condition at room temperature. The paraspinal muscles of each specimen were removed, keeping the interspinous ligaments, supraspinous ligaments and intervertebral disc intact.

The caudal and cranial ends of the motion segment were potted using polyester putty, and an accelerator was added to shorten the hardening process. Potting was employed to ensure that the intervertebral disc plane was horizontal in all specimens. Following specimen preparation, they were divided into three groups: a control group consisting of intact specimens, a destabilized group, and a Midfix group. The destabilized group and the Midfix group underwent a surgical procedure that involved cutting the interspinous and supraspinous ligaments. Lastly, biomechanical tests were conducted.

Biomechanical Tests

Biomechanical testing was performed utilizing the axial-compression system (AG-I 10-KN, Shimadzu, Japan). This system incorporates TRAPEZIUM 2 and CCD camera-extensometers (non-contact video extensometer DVE-101/201, Shimadzu, Japan) to obtain measurements without direct contact with the specimen. Figure 3 depicts an illustration of the specially designed fixture used in the experiments.

The potted intact motion segment was fixed on the testing frame. Axial loads were applied to the anterior, posterior, right, and left sides of the center of motion, producing bending forces for FE movements and right-left bending (RB-LB), respectively (Figure 4).

In a neutral position, 400 Newton (N) axial loads were applied to the spine and were increased up to 8400 N-mm generated through the axial movement to achieve the FE and right-LB motions[16]. During testing, the extensometer recorded the intervertebral displacement at decompression levels L4-5. Gauge marks were inserted into the specimen with pins to measure the superior-inferior and anterior-posterior displacement. The two non-contact cameras captured images of the gauge marks. The displacement of gauge marks on the CCD screen was converted into actual displacement. This conversion process involved recording displacement values via two non-contact cameras connected to a personal computer linked to the test machine.

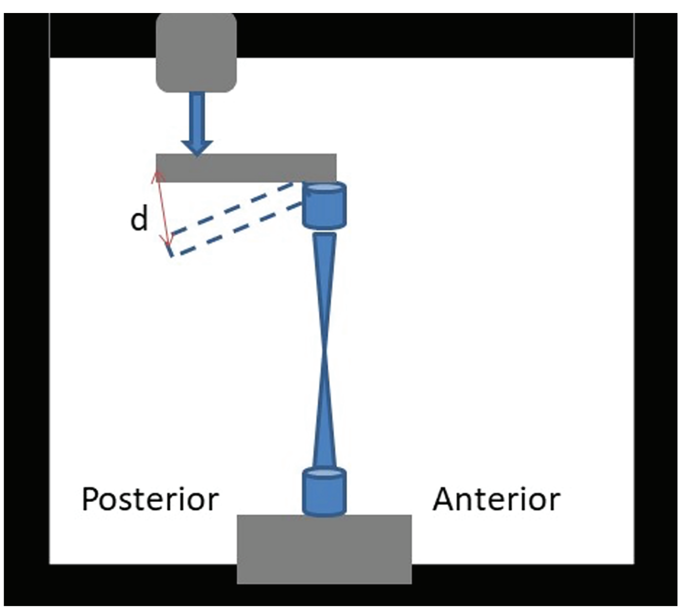

Figure 3. Illustration demonstrates the biomechanical setup. Value of "d" represented the displacement (mm) of intervertebral distance while applying axial force

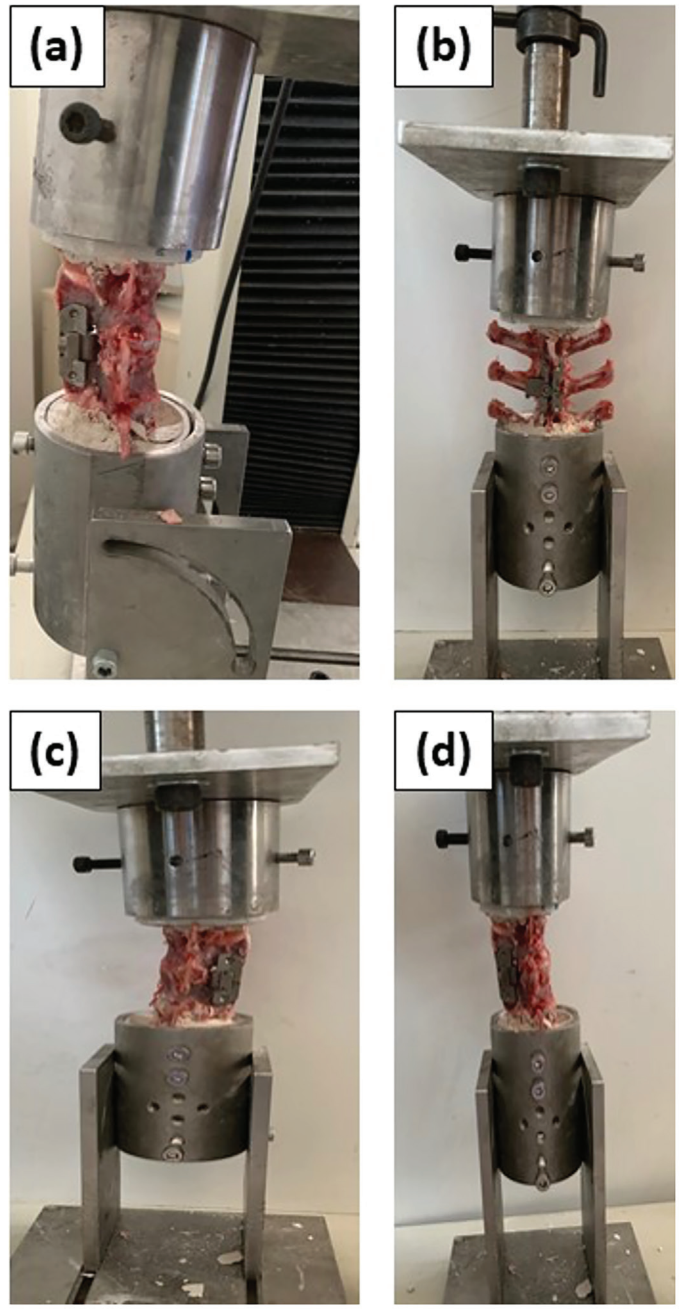

Figure 4. Motion segment implanted with Midfix interspinous fusion device with various positions in Biomechanical test (a) Flexion test (b) Extension test (c) RB test (d) LB test
RB: Right bending, LB: Left bending

Statistical Analysis

The distribution of the data was evaluated using the Shapiro-Wilk test. Continuous variables are presented as mean and standard deviation (SD). The differences in mean values for the specimens were evaluated using the paired samples t-test. All statistical analyses were conducted using SPSS for Windows (version 22.0; IBM Corp., Armonk, NY, USA). A significance level of p<0.05 was deemed statistically significant.

RESULTS

The mean and SD displacement distances for the vertebrae in FE and right-LB motions are presented in Table 1.

The motion of the destabilized spine increased significantly in extension by 32.4%. However, placement of the Midfix device decreased the extension by 43.2% compared with the intact spine.

Destabilization of the spine increased the flexion range by 57.8%. After implantation of the Midfix device, a 59.4% decrease in the range of motion was observed compared with the control specimen (p<0.05).

The RB range increased by 67% in the destabilized spine specimen. Implantation of the Midfix device resulted in a 22.2% decrease in RB range compared with the destabilized spine. However, the Midfix device did not produce an improvement in RB stiffness, and a 30.2% increase was observed in the range of motion compared with the intact spine.

The range of motion for LB was 46% in specimens with ligaments removed compared with the control specimens. Unlike RB, the Midfix device improved LB stiffness and decreased the range of motion by 25.6% in the destabilized spine compared with the intact spine.

A significant reduction in the degree of displacement between the control and Midfix groups was observed for flexion (6.4±0.5 vs. 2.6±0.8, p=0.015), extension (3.7±1 vs. 2.1±0.5, p=0.048), and LB (3.9±0.7 vs. 2.9±0.6, p=0.021). Nonetheless, no statistically significant difference was noted in the degree of RB between the control and Midfix groups (4.3±0.7 vs. 5.6±1.1, p=0.06).

Table 1. Mean and SD values for extension-flexion and RB-LBs

	Control group (n=6) Mean ± SD (mm)	Destabilized group (n=6) Mean ± SD (mm)	Midfix group (n=6) Mean ± SD (mm)
Flexion	6.4±0.5	10.1±2.7	2.6±0.8
Extension	3.7±0.1	4.9±0.5	2.1±0.5
Right bending	4.3±0.7	7.2±1.2	5.6±1.1
LB	3.9±0.7	5.7±0.9	2.9±0.6

SD: Standard deviation, Mm: Millimeter, RB: Right bending, LB: Left bending

DISCUSSION

In our study, the Midfix device produced improvements in FE and LD stiffness compared with both intact and destabilized spines. However, no significant improvement was observed in RB range in specimens implanted with the Midfix device. These results suggest that Midfix may be clinically useful in the restabilization of the destabilized spine regarding FE and LB motion. The device allowed less motion on FE and right-LB than the destabilized spine alone. Comparison of the results of intact and Midfix-implanted specimens revealed more rigid fixation in the sagittal plane and non-rigid fixation in the coronal plane with the Midfix device.

Techy et al.[16] reported a 74% decrease in FE motion, 5% decrease in LB, and 0.4% decrease in RB in ISD-instrumented spines. ISDs provided as much FE stability as bilateral pedicle screw instrumentation; however, ISDs produced minimal rigidity in bending motions when used alone. These results are consistent with our findings. Lindsey et al.[17] performed a biomechanical study on interspinous spacers (X Stop; SFMT, Concord, CA, USA) and found a decrease in FE range and no significant change in AR or LB. Wilke et al.[18] reported a reduction in only FE motion in a biomechanical study of four different ISDs. Karahalios et al.[5] implanted an ISD to support an L4-L5 ALIF procedure and observed more stiffness stability in FE and less in AR or LB, which is in line with previous studies. Tsai et al.[19] performed a biomechanical study on the Coflex™ interspinous fixation device in human cadaver spines.

The Coflex device ensures non-rigid fixation and can return a partially destabilized spine to the intact state regarding flexion, extension, and axial rotation.

Extensometers have been widely used in the literature. Shono et al.[20] used an extensometer to compare the stiffness and unit motion of a calf spine with anterior instability. Chen et al.[21,22] performed a biomechanical study on porcine spines with three different sagittal alignment patterns: normal, kyphotic, and lordotic. The intervertebral displacement of adjacent segments was measured using an anterior extensometer. Gurr et al.[23] measured intervertebral displacement through a corpectomy site using an extensometer to compare the stability of different types of posterior instrumentation on a calf spine model. In our study, we used an extensometer to compare the differences in intervertebral displacement between intact, destabilized, and Midfix-implanted spines.

We chose a moment of 8400 N-mm because recent studies reported that the maximal moment was reached at 8400 N·mm, which stopped the flexion or extension motion. During the extension of the spine, the facet joints lock and prevent more posterior vertebral displacement, and the moment increases quickly to the endpoint of 8400 N-mm[24].

In our study, we conducted excision of the interspinous ligaments while leaving the disc intact. Notably, the displacement values observed in our study remained unaffected by disc height.

However, there were variations in intradiscal pressure (IDP) across different implants. Specifically, the pedicle screw system exhibited the lowest IDP at the surgical level across all motion modes, albeit with a significant increase in IDP at adjacent levels. Shen et al.[25] conducted a finite element studyand reported that the DIAM™ device demonstrated similar IDP to the intact model, particularly in lateral bending and rotation. Conversely, other devices such as Coflex-F and Wallis exhibited higher IDP at the surgical level, albeit with minor increases at adjacent levels. This observation suggests that ISDs may not significantly affect IDP at adjacent levels, potentially offering benefits in preventing adjacent segment degeneration over the long term. Further clinical investigations focusing on the effects of Midfix on IDP are warranted to provide additional insights into its impact. The results for FE were expected and relevant as Midfix is located at the midline, between the spinous processes. However, the decline in LB motion was surprising considering the position of the ISD. Moreover, we observed an increase in RB motion in the destabilized spines implanted with Midfix compared with the intact spines. One explanation may be that the locking hole was positioned at the right side, leading to less torque, so it could not resist the torque of the system as the distance of the force arm was minimal. The left side had a longer force arm distance, so the ISD could resist the force on the system during LB motion. Moreover, the differences between human and lamb spinal structures could influence these results, and this issue must be considered. An updated design of the ISD in which the locking part is located more medially would balance the range of motions in RB and LB.

The impact of implant size, placement, and fixation on both the implanted segment and adjacent segments is paramount. The current body of literature offers various recommendations to address these factors, including measuring the distance between spinous processes or employing device templates to facilitate precise implantation and mitigate the risk of overestimating device size. However, consensus regarding the most suitable implant size remains elusive. Anasetti et al.[26] noted that device size and positioning significantly affect the neutral position's displacement. While small devices offer limited spinal stabilization, larger devices may increase the risk of disc overload due to a kyphotic position.

Zheng et al.[27] conducted a biomechanical study assessing various sizes of the same device. Their findings suggested that employing a larger device may be advantageous in treating patients with lumbar spinal stenosis. For patients with degenerative disc disease, implant placement with a spacer height matching the distance between interspinous processes proves effective. Therefore, selecting the appropriate implant size hinges on the patient's clinical scenario.

In our study, we maintained consistency by employing identical-sized devices across all specimens. Nevertheless, future research endeavors should explore the utilization of varying device sizes to provide a comprehensive assessment of their impact. Fusion devices offer rigid stabilization at the level of the spacer body and promote fusion through biomechanical means. These devices can be used in isolation, in conjunction with cages, or alongside other spinal devices to induce fusion, akin to more invasive fusion techniques.

From a biomechanical perspective, it's crucial to acknowledge that ISDs may induce segmental kyphosis in the spine, which typically exhibits lordosis. This discrepancy could potentially lead to anterior disc overload if ISDs are employed independently. However, when ISDs are combined with cages, this focal kyphosis may adversely affect interbody fusion and graft integration. Our study focused solely on evaluating ISD use in isolation; hence, future investigations should be designed to address these concerns.

Conversely, biomechanical studies suggest that ISDs may yield comparable outcomes to pedicle screw rod application in limiting FE motion, with potential advantages in limiting axial rotation and lateral bending. However, our analysis only accounted for motion in the sagittal and coronal planes (FE, lateral bending, and axial rotation). Therefore, it is imperative to conduct further investigations to assess the effects of ISDs under different loading conditions, including axial rotation.

There are some limitations to our study. First, this study was conducted on lamb lumbar spine specimens, which did not have physiological structures including, spinal alignment, and the number of lumbar segments in lamb spines differ from those in human cadaveric spines. However, in the literature, numerous studies report that animal spines are often the preferred choice for conducting such experiments due to their convenience and suitability for biomechanical research[28,29].

Rigid fixation can cause hypermobility in the adjacent segment, which leads to acceleration of degenerative conditions[20,30]. The range of motion of adjacent segments was not evaluated with the insertion of the Midfix. In our study, we observed a 43.2% decrease in extension and a 59.4% decrease in a flexion. Although this finding indicates the theoretical disadvantage of Midfix, clinical results might not be in line with these results. In the testing methodology employed in this study, the application of load was dynamically optimized, aiming to minimize off-axis loads. This approach ensured unconstrained pure moment loading conditions throughout the test. Consequently, future analysis of long-term clinical results will be essential for a comprehensive understanding of the findings.

The primary goal of ISD is stabilization of the unstable spine. The secondary goal is a reduction in the pressure on the disc by distracting the interspinous space and unloading the facet joints. In our study, confirmation of whether these goals were biomechanically achieved was not performed. Therefore, other biomechanical studies should be conducted to verify the treatment goals of the Midfix.

CONCLUSION

Destruction of the supraspinous and interspinous ligaments can lead to the development of instability. The Midfix device provided the required stability in the absence of the interspinous and supraspinous ligaments. The Midfix device had a more pronounced effect on FE than other loading modes. Therefore, surgeons should take care when using Midfix for the stabilization of bending and rotational movements because of the lack of information about its stabilizing effect.

Footnote

Ethics Committee Approval: This study was approved by the Dokuz Eylül University Non-Interventional Research Ethics (approval number: 2021/28-03, date: 13.10.2021).

Informed Consent: As this study involved animal specimens, no patient informed consent was obtained.

Authorship Contributions

Surgical and Medical Practices: E.Ş., F.E., A.K., J.B., Concept: E.Ş., F.E., S-H.L., S-H.S., J.B., Design: E.Ş., F.E., A.K., Data Collection or Processing: E.Ş., S-H.L., S-H.S., J.B., Analysis or Interpretation: E.Ş., Literature Search: E.Ş., Writing: E.Ş., F.E.

Conflict of Interest: The authors have no conflicts of interest to declare.

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RETROSPECTIVE REVIEW OF SPINOPELVIC PARAMETERS IN PATIENTS WHO HAD SURGERY FOR LUMBAR DISC HERNIA: CROSS-SECTIONAL CASE STUDY

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ABSTRACT

Objective: This study examined the effect of spinopelvic parameters on the formation of lumbar disc herniation (LDH) in patients who underwent surgery due to LDH was examined. For this purpose, a retrospective cross-sectional analysis was performed on two groups; healthy individuals and those who underwent surgery.

Materials and Methods: Correlation between clinical examination, plain radiography, and magnetic resonance imaging was performed for patients with LDH. Patients who underwent surgery for L4-5 and L5-S1 levels were included in the study. Healthy controls were included in Group 1, and patients who underwent LDH surgery were included in Group 2. Spinopelvic parameters (LL, L1-L4, L4-S1, SS, PI, PT angles) were measured using Surgimap. The obtained data were statistically compared using SPSS.

Results: There was no difference between the two groups in L1-L4, SS, PI, and PT measurements. LL (p=0.004) and L4-S1 lordosis angles (p=0.001) were found to be lower in Group 2 than in Group 1. In Group 2, no difference was found in any parameter regarding the formation of disc degeneration at a single or multiple levels. In group 2, PI values of the L4-5 disc level were higher than those of the L5-S1 disc level (p=0.032).

Conclusion: There were no statistically significant differences between groups 1 and 2, except for LL. Decreased LL is a risk factor for surgery for disc herniation.

Keywords: Spine surgery, lumbar disc herniation, spinopelvic parameter

INTRODUCTION

In modern societies, one of common causes of lumbago and radiculopathy become lumbar disc herniation (LDH). In some cases, functional loss in lumbar movements can significantly restrict daily activities, leading to a decrease in productivity and working time, which in turn affects the cost of living and work. The literature suggests that the clinical symptoms of LDH are associated with sagittal imbalance of the spine[1]. Sagittal balance refers to the state in which a person can maintain a stable posture with minimum muscle expenditure.

Achieving sagittal balance requires the coordinated function of the spinal and pelvic bone structures, the integrity of the disc material, the mechanical behavior of the ligaments, muscle strength, muscle endurance, and the interaction among these components[2]. Spinal sagittal imbalance has been primarily assessed through radiological parameters in various studies[3,4].

One of the key spinopelvic parameters, pelvic incidence (PI), has been debated regarding its involvement in the pathogenesis of LDH. While some studies have found a difference in PI between LDH patients and the general population [5,6], others have reported no such difference[7,8]. On the other hand, lumbar lordosis (LL) appears to be associated with PI and is thought to influence the disc degeneration process[9]. As a parameter, PI fixes reflect the shape and size of the pelvis. PI and LL are in a dynamic relationship and they explain the importance of lumbar postural curvature for maintaining spinal balance[10]. There are very few studies that have comprehensively examined the relationship between the degree of lordotic curve and low back pain[9,11]. LL is closely related to other spinopelvic measurements such as sacral tilt (SS) and pelvic tilt (PT). These values have important roles in regulating the sagittal balance. To compensate for this sagittal imbalance, the pelvis tilts backward by increasing PT and decreasing SS, thus adjusting posture[6]. Less degeneration

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is observed in LDH patients at an early age, suggesting that the regulatory mechanisms maintaining sagittal balance are more effective during this period. This may help explain the sagittal morphology observed in LDH patients.

In this study, the effect of spinopelvic parameters on LDH formation in patients operated for LDH was examined. For this purpose, radiographic data of a patient group (range of age: 20-50) underwent surgical process for LDH. A control group of healthy individuals who did not undergo lumbar surgery were retrospectively examined and compared.

MATERIALS AND METHODS

The approval for this study by the Clinical Research Ethics Committee of the Bursa Uludağ University Faculty of Medicine (approval number: 2011-KAEK-26, date: 18.10.2023). In this study, patients whose diagnosis was confirmed by magnetic resonance imaging (MRI) after clinical examination in the orthopedics and traumatology clinic between June 2019 and September 2023, who did not respond to conservative treatment and who were operated on due to LDH, and cases of appropriate age and gender as a control group were directly examined. The radiographs were evaluated retrospectively. The control group consisting of healthy individuals was called Group 1, and patients between the ages of 20 and 50 who had undergone surgery due to LDH were called Group 2. All surgical procedures were performed by a single surgeon. Exclusion criteria were as follows: patients with recurrent disc disease who previously underwent surgery for LDH, patients with additional spinal deformity or degenerative changes, patients who underwent surgery at more than one level, and patients over 50 years of age. Patients in whom reference anatomical regions could not be selected for measurement or whose preoperative lumbar MRIs could not be obtained along with films taken at inappropriate doses were also excluded from the study. Group 2 included patients who operated for L4-5 and L5-S1 levels, while a patient who operated for L3-4 level was excluded from the study. Retrospective evaluation was performed with preoperative standing lumbar two-way radiographs and radiographs covering the entire lumbar region from the thoracolumbar level to the hip joints. In both groups all parameters (LL, SS, PI, PT, L1-L4 and L4-S1) angles were measured on standing lateral radiographs using the Surgimap (NY 10016, USA) program by a single person who performed the surgical procedure (Figure 1). Measurements of both groups were made by a single person who performed the surgical procedure with the Surgimap program. By looking at the preoperative MRIs of Group 2 cases, the disc levels where the operation was performed and the presence of an additional degenerative disc level were determined. Two groups were compared statistically by measuring spinopelvic parameters (LL, L1-L4, L4-S1, SS, PI, PT angles).

Statistical Analysis

Use the Shapiro-Wilks test to test whether the data are normally distributed. If the data were normally distributed, comparisons between groups were made using the Student t-test and the results were interpreted as mean ± standard deviation. If the data were not normally distributed, comparisons between groups were made using the Mann-Whitney U test and descriptive data were given as mean (minimum-maximum) values. Comparisons of categorical data between groups were made using the Pearson chi square test and descriptive statistics were given as n (%). The significance test was $\alpha=0.05$. Analysises were performed using the SPSS (v25).

RESULTS

The files of 186 operated patients who had diagnosis of LDH were retrospectively examined. Age and gender comparisons were also made between Group 1 and Group 2. There were 18 men and 18 women in both groups. In this study, no statistically significant difference was found according to gender. While the mean and standard deviation according to age was 40.36±6.26 in Group 1, it was 40.69±6.21 for Group 2 (p=0.821).

At the evaluation for MRIs in Group 2, all cases were shown in axial T2 MRI images according to the Michigan State University (MSU) classification. In the MSU classification the size and location of disc herniation are measured at the level of maximal extrusion in reference to a single intra-facet line drawn transversely across the lumbar canal, to and from the medial edges of the right and left facet joint articulations. To portray the size of disc herniation, the lesion is described as 1, 2, or 3 (Figure 2). To further qualify location of the disc herniation, the lesion is described as A, B, or C. The right and left central quadrants represent zone-A. The right and left lateral

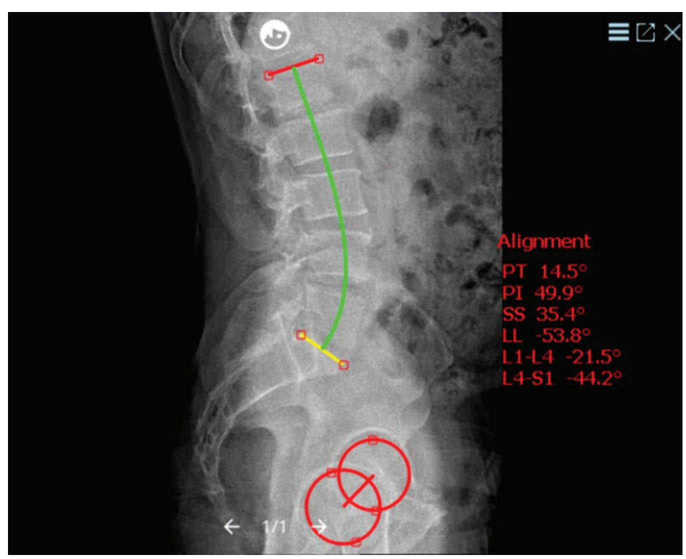

Figure 1. Measurements made using the Surgimap program
PT: Pelvic Tilt, PI: Pelvic Incidence, LL: Lumbar lordosis, SS: Sacral Tilt

quadrants represent zone-B. A third zone-C is represented at the level of the foramen by the area that extends beyond the medial margin of either facet joint, past the borderline of the lateral quadrants (Figure 3). In accordance with the clinical findings; 36 cases with moderate and severe disc herniations, consisting of patients in groups 2 and 3 according to disc herniation size and A, AB and B according to localization, were included in the study, (Figure 2, 3)[12]. Group 1 consists of 367 cases from the hospital database who complained of low back pain or had lumbar bidirectional radiography taken for the differential diagnosis of lumbar pathology; It was created with 36 cases of statistically similar age and gender and no spine pathology was detected in the bidirectional radiographic images.

The significant difference was not detected between the Group 1 and the Group 2 according to PT, PI, SS and LL (Table 1). In terms of LL, there was a significant difference between the Group 1 and the Group 2. The LL values are higher in the Group 1 compared to the Group 2 (p=0.004) (Table 1). Although there were no difference between the two groups for PT, PI and SS, but LL was significantly lower in the Group 2 (Table 1).

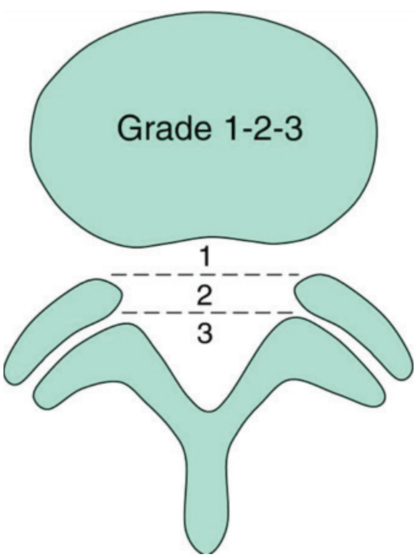

Figure 2. Grading the disc herniation for size. Grade 1 lession have little impact and grade 3 have the most impact on nevre compression

In terms of L4-S1 lordosis angle, a significant difference was not observed between Group 1 and the Group 2. The L4-S1 values was higher in Group 1 (p=0.001) (Table 1).

In Group 2, the number of men with one disc degeneration was 9 (45.0%), the number of women is 11 (55.0%); with more than one disc degeneration, the number of men is 9 (56.3%), the number of women is 7 (43.8%). To gender, there was no difference in the Group 2 with one disc degeneration and more than one disc degeneration (p=0.737). There were no significant differences in the Group 2 with one disc degeneration and with more than one disc degeneration in terms of age, SS, LL, PT, PI, L1-L4 and L4-S1 (Table 2).

In comparison according to the LDH level, the number of men in the L4-5 group was 8 (53.3%), the number of women was 7 (46.7%), the number of men in the L5-S1 group was 10 (47.6%), and the number of women was 11 (52.4%). The significant difference was not detected according to LDH level to gender as statistically. The significant difference was not detected according to LDH level in terms of age, SS, LL, PT, L1-L4 and L4-S1 (Table 3). The significant difference was not detected in terms of PI for LDH level. The PI values of the L4-5 disc level was higher than L5-S1 disc level (p=0.032) (Table 3).

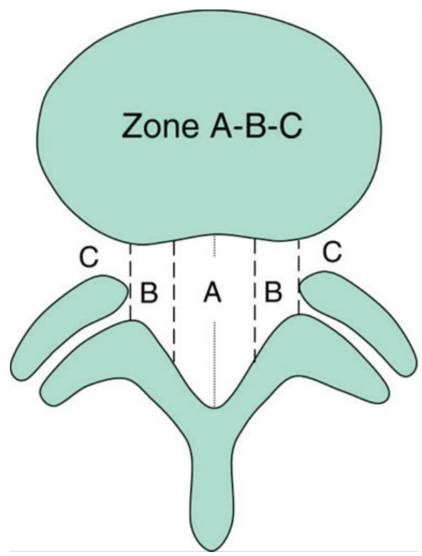

Figure 3. Zoning the disc for location. Lesions have more impact in tighter zone B and C

Table 1. Comparisons according to control and operation group

	Grup 1 (n=36)	Grup 2 (n=36)	
	Mean ± SD/Median (min.-max.)	Mean ± SD/Median (min.-max.)	p-value
PT	15.70 (1.9-27.3)	13.65 (5.7-32.3)	0.551##
PI	48.80±10.64	46.76±9.20	0.388#
SS	33.58±8.99	31.67±7.25	0.323#
LL	57.20±12.49	49.12±10.44	0.004#
L1-L4	23.15±8.16	20.98±6.74	0.223#
L4-S1	46.29±8.39	39.04±8.67	0.001#

#Student's t-test, ##Mann-Whitney U test. PT: Pelvic tilt, PI: Pelvic incidence, LL: Lumbar lordosis, SS: Sacral tilt, SD: Standard deviation, min.-max.: Minimum-maximum

Table 2. Comparison according to disc degeneration in Group 2

	Disc degeneration		
	One level (n=20)	More than one (n=16)	
	Mean ± SD/Median (min.-max.)	Mean ± SD/Median (min.-max.)	p-value
Age	41.25±5.57	40.00±7.04	0.556#
PT	13.30 (5.70-25.8)	13.65 (7.00-32.30)	0.888##
PI	46.90 (33.50-57.90)	47.15 (32.20-69.90)	0.498##
SS	30.76±7.58	32.80±6.88	0.409#
LL	50.09±11.98	47.91±8.35	0.542#
L1-L4	21.60 (10.7-31.8)	22.15 (1.9-28.9)	0.718##
L4-S1	39.40±10.63	38.60±5.64	0.789#

#Student's t-test, ##Mann-Whitney U test. PT: Pelvic tilt, PI: Pelvic incidence, LL: Lumbar lordosis, SS: Sacral tilt, SD: Standard deviation, min.-max.: Minimum-maximum

Table 3. Comparison according to LDH level in Group 2

	LDH level		
	L4-5 (n=15)	L5-S1 (n=21)	
	Mean ± SD/Median (min.-max.)	Mean ± SD/Median (min.-max.)	p-value
Age	41.20±4.74	40.33±7.17	0.686#
PT	14.6 (9.1-31.5)	11.7 (5.7-32.3)	0.109##
PI	50.61±9.50	44.01±8.13	0.032#
SS	33.57±8.37	30.31±6.19	0.188#
LL	51.09±11.95	47.71±9.26	0.346#
L1-L4	21.66±6.36	20.50±7.11	0.616#
L4-S1	40.27±10.27	38.16±7.47	0.479#

#Student's t-test, ##Mann-Whitney U test. PT: Pelvic tilt, PI: Pelvic incidence, LL: Lumbar lordosis, SS: Sacral tilt, SD: Standard deviation, min.-max.: Minimum-maximum

DISCUSSION

The lumbar region provides the connection between the trunk and lower limbs in maintaining the sagittal posture. If the spine is imagined as a pillar of a crane, the total contact pressure into the lumbar intervertebral disc can be measured by the sum of body weight pressure and posterior paraspinal muscle force pressure. As the LL is greater, the effect of the contact force acting on the posterior elements will be greater. The contact force shifts forward towards the intervertebral discs with the low PI and LL. As a result, the vertebral endplates are close to the horizontal plane. The pressure of vertical contact force increases and the resulting intradiscal pressure increases significantly[11]. Pourabbas Tahvildari et al. [11] found low-angle values of PI and LL in patients with LDH.

Yokoyama et al.[13] also stated that compared to healthy individuals, a significant decrease in LL and SS and an increase in PT and sagittal vertical axis were observed in patients with LDH. Comparing of Group 1 and Group 2; L1-L4 lordosis, SS, PI and PT angular values were similar. LL was found to be lower in Group 2 (p=0.004). The decrease total LL was found to be due to L5-S1, which was found to be statistically low (p=0.001). Since two-way lumbar radiographs that could not be taken standing or lying down due to severe LDH symptoms were not included in the study and standard patient positioning was performed in lumbar radiographs, it can be claimed that there was a loss of LL in the surgery group and this could cause lumbar disc pathology.

Poonia et al.[14] stated that in patients with high PI and SS, increased shear stress in the lumbosacral junction will increase disc degeneration and prolapse by causing more tension in the anterior and posterior facet joints of the intervertebral disc in the L5-S1 distance. In the same study, it was stated that the increase in LL, SS, PT and PI caused in increased risks of pathology in discs of L4-L5, while the increased angles of PT and LL caused an increase in disc pathology in L5-S1. To Poonia et al.[14] patients with higher PI and SS and therefore higher LL values were found. In this study, while SS, PI and PT values in Group 2 did not vary compared to the control group, LL was found to be lower.

In the study of Barrey et al.[15], It has been shown that certain sagittal changes in the spine may increase the risk of LDH[15]. A straight spine profile with low LL was associated with an high risk of disc degeneration at L4-L5 and L5-S1 levels. These individuals have developing early-onset disc degeneration[16,17].

In this study group, in all spinopelvic parameters, although the significant difference was not observed in LL of L1-L4 in Group 2 (p=0.223), a decrease in the total LL angle was detected (p=0.001) due to the difference in the L4-S1 lordosis angle (p=0.004).

Liu et al.[18] emphasized that PI, which has a significant effect on lumbar disc degeneration, being too large or too small may predispose to the emergence of lumbar disc degeneration. They also reported that L5-S1 disc degeneration had a significant effect on pelvic postural parameters (PT, SS). It has been stated that L5-S1 degeneration was the main causal factor of pelvic posterior rotation and compensatory process. In this study, no significant difference was found between the groups in the PI value, which is a pelvic constant parameter. In group 2, no statistical difference was found in spinopelvic parameters when compared with 20 patients with single level disc degeneration and 16 patients with multiple level disc degeneration. However, when the levels of disc herniation were considered, PI value was lower in the L5-S1 group (21 cases) than L4-L5 group (15 cases) (p=0.032).

Study Limitations

The limitations can be listed as follows: Classification can be made according to demographic characteristics and pathophysiology of LDH. Due to the limited number of cases, the professions and body mass index of the cases could not be evaluated in the study. Due to the lack of control group MRIs, possible disc pathology that did not show clinical findings could not be ruled out. The study can be multi-center and have more descriptive features with a larger number of patients.

CONCLUSION

In this study, the effect of spinopelvic parameters within the individual's anatomical and physical structure was examined, apart from external factors that initiate degeneration in LDH formation and cause deterioration of the compensatory mechanism in the process leading up to surgery. No difference was found between healthy and operated groups as statistically, except for LL. In particular, the effect of PI, which is an individual-specific fixed parameter, on LDH formation was not detected. Decreased LL may be a risk factor for disc herniation requiring surgical treatment. The relationship between spinopelvic parameters and LDH needs to be examined in new studies that are multi-center, more comprehensive and include a larger number of patients.

Footnote

Ethics Committee Approval: The approval for this study by the Clinical Research Ethics Committee of the Bursa Uludağ University Faculty of Medicine (approval number: 2011-KAEK-26, date: 18.10.2023).

Informed Consent: Retrospective study.

Authorship Contributions

Surgical and Medical Practices: B.A., Concept: B.A., H.Ü., K.Y., Ü.Ö.G., Design: B.A., H.Ü., K.Y., Ü.Ö.G., Data Collection or Processing: B.A., H.Ü., K.Y., Ü.Ö.G., Analysis or Interpretation: B.A., Literature Search: B.A., Writing: B.A., H.Ü., K.Y., Ü.Ö.G.

Conflict of Interest: The authors have no conflicts of interest to declare.

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ORIGINAL ARTICLE

WIDE RESECTION IN SACRAL OSTEOBLASTOMA: CASE SERIES

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ABSTRACT

Objective: The purpose of this study was to assess the outcomes of wide resection for sacral osteoblastoma (OB).

Materials and Methods: A review of our database revealed 6 cases of OB located in the sacrum. Localized pain in lesions that did not fully resolve although medical treatment was observed in all 6 cases. Surgical treatment consisted wide resection. The average time between diagnosis and surgery was 30 (24-36) months, and the average age at surgery was 14 (8-20) years.

Results: Postoperatively, the mean follow-up period was 74.3 months (24-110). At final followup, we did not encounter any complications, recurrence, spinal instability, and neural damage were not observed as a result of the removal of lesions in the sacrum area. The preoperative mean Visual Analog Scale score was 8 before treatment and 0 at the final follow-up.

Conclusion: Wide resection is a safe and effective treatment option for patients with sacral osteoblastoma.

Keywords: Wide resection, osteoblastoma, sacrum

INTRODUCTION

Osteoblastoma (OB) is a rare benign primary bone tumor with less sclerotic borders and no reactive perilesional bone formation. It grows slowly and is larger than 20 mm[1-4]. OB is commonly seen in adolescents under the age of 20[5]. OB is clinically divided into two types: conventional OB and aggressive OB (in older patients). Pain is the first clinical symptom. Pain is caused by the excessive production of prostaglandins. Moreover, OB is less responsive to non-steroidal anti-inflammatory drugs (NSAID)[6-10].

OB is seen more common in men. It is mostly located in the spine (30-50%), especially in the posterior elements (pedicle and lamina). But it can also develop from the vertebral body. It is less likely to be seen in the sacrum than in other spinal segments[9,11,12]. Due to the rarity of OB in the sacrum, there are few studies in the literature regarding its treatment[6,13-15]. Thus, this study aims to evaluate the clinical success of wide resection for OB located in the sacrum.

MATERIALS AND METHODS

This single-center retrospective study was carried out at the University of Health Sciences Turkey, İstanbul Training and Research Hospital in accordance with the Declaration of Helsinki guidelines (approval number: 66, date: 06.09.2024). An opt-out form, available on the hospital's website, was used to obtain informed consent. All participants received thorough information and gave their informed consent. Furthermore, all patients in this study provided informed consent prior to inclusion.

All patients were presented with pain in the lumbosacral and sacrococcygeal regions. Concurrently, one patient had pain localized at the S2-S3 level, another patient had pain localized at the S3-S4 level and 4 patients had pain localized at the S4 level. Patients preoperative and postoperative pain were evaluated with Visual Analogue Scale (VAS). All patients had no neurologic deficit, and their complaints were partially reduced with the use of NSAIDs. Local tenderness in the complaint area was present in 100% of the patients.

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To define the lesions and prepare for preoperative planning, all patients were examined with pelvic and positron emission tomography (PET) computed tomography (CT) and magnetic resonance imaging (MRI) which were identified using the hospital's Picture Archiving and Communication System. A hundred percent of the lesions were larger than 2 cm. The patients went under the procedure of biopsy with the guide of the C-arm fluoroscopy and biopsy sample material was obtained. The samples were investigated in the pathology department, confirming the OB diagnosis. With the confirmed pathological diagnosis and correlated clinical evaluation, patients were staged as stage IIA and IIB according to the Enneking classification (Table 1).

Patients with no neurological deficits & no functional joint range of motion limitation and with the OB diagnosis confirmed by pathological assessment were included in our study. There was no strict exclusion criteria applied due to the rarity of OB in the sacrum.

All patients in this study also were thoroughly informed prior to surgical intervention and gave their informed consent. Under general anesthesia, with appropriate prepping and sterile draping on prone positioning, the posterior approach midline incision was used to expose both sides of the sacrum. Distally based V-shaped incision was made in the lumbosacral fascia, iliac crest was aimed and incision had ended when this landmark is reached. To achieve exposure the posterior aspect of the sacrum, subperiosteal elevation of the lumbosacral musculature was performed by releasing the multifidus distally and elevating it as a flap. Afterwards, OB lesion was widely resected within the proper resection margin area. The operation was concluded after gentle repositioning and repair of the erector spinae muscles and closure of the subcutaneous tissues and skin in layers. Dissected material was sent to pathology department for further confirmation. All patients that underwent wide resection through the posterior approach were without preoperative embolization. The interval between diagnosis and operation was approximately 30 months.

RESULTS

Between 2013 and 2020, wide resection was performed on 6 patients with Enneking classification stage 2 OB in the sacrum. The sample size of the study is total of 5 patients included; while 5 were male (83.3%), 1 was female (16.6%) and the mean age was 14 (8-20) years. The localized lesions in the patients were at the S2-S3 level in one patient, at the S3-S4 level in one patient, at the S4 level in 2 patients, and at the S4-S5 level in 2 patients.

The masses of all patients that were removed by wide resection using a posterior approach were confirmed OB diagnosis, with preoperative biopsy sample material and postoperative resected tissue material via pathology department. Reconstruction was not applied or required to any patient. There was no excessive bleeding during surgery in any of the procedures, further no significant hemogram abnormalities observed amongst all the patients during surgical follow-up. No postoperative complications were observed in any patient. Moreover, no recurrences occurred in any of the patients during follow-up.

After the wide resection procedure, the patient's pain complaints were evaluated with VAS. Between the comparison of ratings preoperative and postoperative, mean average of preoperative ratings were recorded as 8 and mean average of postoperative ratings were recorded as 0. The patients were not evaluated only according to their pain complaints in their clinical evaluation. Preoperatively, no functional joint range of motion limitation or no neurological deficits were observed in any of the patients. Postoperatively, there were no changes in their functional joint range of motion or neurological evaluation. Moreover, according to the clinical assessment of patients preoperatively and postoperatively using American Spinal Injury Association impairment scale, all the patients can be graded as E (sensation and motor function are graded as normal in all segments).

DISCUSSION

OB was first described as giant osteoid osteoma (OO) in 1954[16]. Lichtenstein[17] and Jaffe[18] defined OB as a separate clinical and morphological diagnosis from OO. Tumors with a diameter of ⩽1 cm were classified as OO, while those with a diameter of ⩾2 cm were classified as OB. Other criteria for diagnosing tumors between 1 cm and 2 cm included the relevant bone, site, presence of nidus, and presence of peripheral sclerosis. Compared to OO, radiographic features of OB are variable and non-specific, but they typically indicate a benign process. The lesion is typically oval or round, expandable, well-defined, and radiolucent. The central part can be completely lytic, but there

Table 1. Enneking staging for malignant musculoskeletal tumors; based on surgical grade, local extent, and presence or absence of metastasis

Enneking staging for malignant musculoskeletal tumors			
Stage	**Grade**	**Site**	**Metastasis**
IA	Low (G1)	Intracompartmental (T1)	No metastasis (M0)
IB	Low (G1)	Extracompartmental (T2)	No metastasis (M0)
IIA	High (G2)	Intracompartmental (T1)	No metastasis (M0)
IIB	High (G2)	Extracompartmental (T2)	No metastasis (M0)
III	Any (G)	Any(T)	Regional or distant metastasis (M1)

is usually some focal calcification. Furthermore, OB exhibits a distinct pain pattern, lacks reactive bone formation, and is larger[8-10]. OB is a slow-growing benign primary bone tumor made up of well-vascularized connective tissue that produces active osteoid and primitive woven bone[9].

In some of the cases, OB can break the cortical bone and can be aggressive, and differential diagnosis of these cases may be more difficult than low-grade osteosarcoma[19-21]. The diagnosis required for treatment is dependent on symptoms, imaging, and pathology[22]. MRI has a limited role in spinal OBs due to the potential for misleading images caused by adjacent inflammatory changes. The visual boundary between bone and soft tissues is less defined, leading to misdiagnosis of aggressive or malignant lesions[23]. For the diagnosis of spinal OB, imaging examinations such as radiography, CT, MRI, and PET have different value, non of them have specificity[24]. Therefore, combining CT, MRI and PET may be beneficial to optimize preoperative diagnosis and care of patients with OBs[25]. A preliminary diagnosis of OB was made clinically in our 6 cases. The diameter of the masses in all cases was larger than 2 cm. Biopsies were taken from the lesions. All pathology results were confirmed as OB. OB has no specific clinical presentation and the primary complaint is progressive pain, which largely depends on location and size. The tumor may enlarge and appear as a palpable mass with associated tenderness and swelling. Neurological symptoms may also be present in the spinal areas[11,26]. The complaints of our patients were pain in the lumbosacral and sacrococcygeal regions. Patients occasionally had complaints of nocturnal pain. Preoperatively, there were no neurological deficits in the patients. All patients stated that their pain was partially relieved when using NSAIDs. None of the patients had a palpable mass on physical examination.

Treatment options for OB include intralesional surgery, wide resection, radiofrequency ablation (RFA), radiotherapy, chemotherapy, and surgical intervention with radiotherapy or chemotherapy[13,14,26,27]. Radiotherapy and chemotherapy can be used as the main treatment or as an adjunct treatment method to surgery. Radiotherapy has been suggested for the treatment of OB in the sacrum, which is difficult to resect completely and carries a risk of complications[15,26]. However, debate continues as to whether it reduces recurrence or not. Radiotherapy has not been shown to improve local control to prevent recurrence after inadequate removal of OB. The disadvantages involve local side effects and the potential for leading to radio-induced sarcomas[26,28].

RFA may be preferred, especially in small lesions and in safe locations. RFA-treated spinal OB cases have been reported in the literature, but there are very few studies and several cases yet[27,29-32]. In RFA application, the minimum safe distance from the bone cortex around the tumor is 2 mm; however, more than 1 mm distance is needed for safety in case of proximity with cerebrospinal fluid and the lesion[33]. Thermal damage to the spinal cord and peripheral nerves is a risk that should be considered prior to RFA since more than 45 °C heating shown to be cytotoxic[27]. The temperature during intervention RFA decreases significantly only beyond the 1 cm distance from the active tip, as the study shows mean maximum temperatures of 69.1°, 51.3°, and 42.5 °C for 1-mm lamella; 59.2°, 46.5°, and 41.1 °C for 3-mm lamella; and 50.6°, 44.8°, and 40.0 °C for 5-mm lamella were measured 0, 5, and 10 mm, respectively, from the periosteum[34]. All in all, due to the risk of thermal damage to adjacent neurovascular tissues RFA has limited spinal application rate.

In the study of Rehnitz et al.[31], there were 2 OBs. One sacral lesion was located in the anterior left sacral ala, directly adjacent to the sacral nerve plexus. They recommend what they consider RFA as the treatment of choice for OB including spinal[31]. One sacral lesion was found in the anterior left sacral ala, right next to the sacral nerve plexus. They suggest RFA as the preferred treatment for OB, such as spinal. Wang et al.[32] also suggest that RFA can be considered as a safe and effective treatment for spinal S2 OB (3 cases). Arrigoni et al.[27] issued a set of 11 patients with OB of the spine who received RFA and achieved total relief in all cases. In another study, Beyer et al.[32] found the technical success rate to be 90.0% and the recurrence rate to be 44.4% after RFA treatment in 10 patients with spinal OB (2 cases in the sacrum)[32].

Considering the success of RFA appliance in some of the studies, the gold standard treatment for OB remains still as surgery. What should be considered in the surgical treatment of OB? First, the tumor should be completely removed, second, the sacral nerve and cauda equina should be preserved[11]. Primary benign spine tumours can be categorized by the Enneking system. Stage 2 and 3 lesions generally require treatment[35]. OB lesions can be evaluated as active OB lesions (Enneking stage 2, S2), and aggressive OB lesions (Enneking stage 3, 3, S3)[6,35]. Intralesional surgery is recommended for grade 2 lesions.

Wide resection is suggested for grade 3 lesions, more serious tumors, or lesions based in areas where a potential local recurrence could prove difficult to treat[6,21,35]. Boriani et al.[6] also recommended spinal S2 OB lesions intralesional curettage and S3 OB lesions block resection as treatment. Because S3-level lesions are aggressive and have a higher recurrence rate[6]. Zoccali et al.[21] nine out of eleven cases required intralesional surgery; wide resection was performed in the other 2 cases. No local recurrence was confirmed at 88 months of follow-up[21]. Intralesional curettage and incomplete resection can lead to recurrence. Ruggieri et al.[14] performed a high number of intralesional for sacral OB's. The recurrence rate was relatively high. They said that inadequate intralesional surgery was associated with a higher rate of local recurrence (40%, 2 local recurrences in 5 cases). Wide resection theoretically minimizes recurrence compared to intralesional resection. However, wide resection can increase the risk of morbidity, especially for lesions proximal to S3. Wide resection of the lesion can often lead to spinal instability and the spine cord or nerve root is as often at risk of damage. The risk of local recurrence in lesions found in the sacrum is higher than in other areas because of complex anatomy and the existence of sacral roots[14].

All things considered, treatment options for OB shows variety [36-38]. For low stage or locally invasive lesions in Enneking classification, surgeons or clinics choice of treatment methodology seems to differ[1,5,13,15]. Due to rarity of the sacral OB, there is no clear consensus on the use of which treatment modality or their combinations[13,14,36]. However, for high grade lesions such as stage 3, wide resection treatment is the treatment modality of choice[37]. Keeping in mind that, treatment aim of OB is complete resection and avoidance of recurrence while preserving adjacent neurovascular tissues, preference of wide resection surgery should be considered in lower stage lesions for better postoperative prognosis[36]. Therefore, in our study, cases that were classified as stage 2 according to the Enneking classification were treated with wide resection surgery to avoid the risk of recurrence. We did not encounter any complications, recurrence, spinal instability or neural damage as a result of the removal of lesions in the sacrum area.

Study Limitations

Our study's major limitations include a retrospective design and a small number of cases.

CONCLUSION

Sacral OBs are rarely encountered. In our series, wide resection was successful in all of the patients. We recommend wide resection surgery in treatment of sacral OB.

Footnote

Ethics Committee Approval: This single-center retrospective study was carried out at the University of Health Sciences Turkey, İstanbul Training and Research Hospital in accordance with the Declaration of Helsinki guidelines (approval number: 66, date: 06.09.2024).

Informed Consent: Retrospective study.

Authorship Contributions

Surgical and Medical Practices: Y.A., Concept: A.Ç., Design: E.Ç., Data Collection or Processing: M.A.A., B.Pe., Analysis or Interpretation: S.B.T., B.P., Literature Search: S.B.T., M.A.A., Writing: A.Ç.

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REVIEW ARTICLE
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A REVIEW OF THE SINUVERTEBRAL NERVE IN DISCOGENIC PAIN: ADVANCES IN DIAGNOSIS AND MANAGEMENT

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ABSTRACT

Chronic low back pain (CLBP) is a leading cause of disability globally, significantly affecting patients' quality of life, and posing a substantial socioeconomic burden. As a major contributor to CLBP, discogenic low back pain (DLBP) is caused by degenerative changes in the intervertebral discs. This review explores the role of the sinuvertebral nerve (SVN) in the transmission of pain associated with DLBP. The complex anatomy of the SVN, with its sympathetic components and multiple levels of origin, contributes to the diffuse and poorly localized nature of pain, thereby complicating the diagnosis and management of DLBP. Imaging techniques like magnetic resonance imaging have limitations in detecting endplate pathologies, whereas more specific approaches such as SVN block and discography offer promise for both diagnosis and pain relief. This review summarizes existing knowledge regarding the role of the SVN in transmitting pain from intervertebral discs and related structures, while also emphasizing the contribution of intervertebral discs to the etiology of discogenic pain.

Keywords: Sinuvertebral nerve, chronic low back pain, discogenic pain, sinuvertebral nerve blocks

INTRODUCTION

For decades, chronic low back pain (CLBP) has been recognized as a major global health concern due to its profound impact on patients' social lives and its widespread disruption(1). CLBP consistently ranks as the leading cause of years lived with disability and has held this position for many years(1,2). Given its substantial socioeconomic burden, CLBP remains a critical issue that demands continued attention.

Low back pain (LBP) is a multifactorial condition, with pain originating from various structures such as facet joints, ligaments, spinal muscles, intervertebral discs, and vertebral endplates (Table 1). As a result, diagnosing LBP can be highly challenging, requiring both clinical expertise and the ability to address complex cases, grounded in a solid theoretical understanding.The primary challenge with LBP is the absence of reliable early diagnostic criteria, which can result in central sensitization, ultimately leading to chronic pain and hyperalgesia(3,4). At this point, central sensitization can have significant consequences. The presence of central sensitization increases the likelihood of treatment-resistant. Furthermore, treatment of the underlying spinal condition may not fully resolve the central sensitization and the associated pain. The pain may persist despite conventional treatments for LBP and often leads to poor surgical outcomes. Prolonged LBP can unfortunately lead to extended opioid use(5). Therefore, we believe that gaining a deeper understanding of discogenic low back pain (DLBP) is crucial for improving diagnosis and developing more effective treatments.

DLBP constitutes one of the most prevalent causes of CLBP, accounting for approximately 26-42% of cases(6,7). It may occur with or without referred pain and arises from degenerative changes within the disc. Typically, this involves distruption of the internal disc, with fissures observed in the annulus fibrosus(7,8). Additionally, disc space narrowing at two or more levels is strongly linked to CLBP(9).

Current understanding suggests that the pathomechanisms of DLBP are complex, involving sensory innervation, inflammation, and mechanical hypermobility(10). Despite extensive research in both humans and animal models, these mechanisms remain

Table 1. Multifactorial pain generators can mainly be discussed in four groups
Myofascial structures
Spinal canal and foramina (stenosis)
Posterior column structures: Facet joint and sacroiliac joint (SIJ) (arthropathy)
Anterior column structures: Disc, Vertebra (Herniated discs, discogenic pain, vertebrogenic pain and compression fractures)

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only partially understood. Discogenic pain is driven by factors such as inflammation, modic changes (MC), and the ingrowth of blood vessels and nerve fibers, with neurotrophins like tumor necrosis factor-α and interleukins promoting nerve growth[10,11]. Additionally, disc degeneration increases collagenase activity, leading to hypermobility and pain. Chronic pain can alter central nervous system (CNS) function, resulting in central sensitization, which manifests as hyperalgesia and allodynia. This central sensitization complicates pain management, requiring targeted treatments beyond addressing spinal problems alone. Managing DLBP effectively requires preventing nerve sensitization, reducing cytokine levels, and controlling disc hypermobility.

Disc aging, disc injury, decreased cellularity, and impaired healing play significant roles in the progression of disc degeneration, which is most commonly observed at the lumbar levels. Notable risk factors include prolonged mechanical loading, trauma, infection, smoking, and genetic predisposition. A classic twin study highlighted the substantial influence of genetic inheritance, estimating heritability at 74%[12].

The sinuvertebral nerve (SVN) plays a crucial role in transmitting pain from axial structures to the CNS. In this review, we explore the pain associated with intervertebral disc disruption and examine the role of the SVN in CLBP. Overall, the study provides a comprehensive overview of how the SVN plays a role in CLBP, emphasizing its diagnostic and therapeutic significance.

MATERIALS AND METHODS

This study aims to provide a comprehensive literature review on discogenic pain to enhance physicians' understanding of the significant factors contributing to CLBP. We systematically researched the published literature for studies focused on patients experiencing CLBP related to issues with the SVN. Data for this review were retrieved from Pubmed, a comprehensive resource that includes peer-reviewed journals, clinical trials, and relevant scientific studies. A systematic search, mostly focusing on articles published between 2000 and 2024, was conducted using relevant keywords, such as "SVN" and "discogenic pain".

Initially, we discuss the clinical presentation of CLBP associated with discogenic pain and the role of imaging in these cases. In this review, we categorize published studies addressing CLBP with a focus on the roles of the SVN.

Additionally, we discuss existing studies on the following topics:

•Clinical Presentation of Patients with LBP Related to Discogenic Pain

•Is Imaging Useful for Patients with LBP Related to Discogenic Pain?

•The Role of SVN in CLBP

•Studies Investigating the Origin of the SVN

•Studies Investigating the Effects of SVN Blocks in DLBP Diagnosis and Management

DISCUSSION

Clinical Presentation of Patients with LBP Related to Discogenic Pain

Since the diagnostic process begins with a suspicion of underlying pathology, clinicians need relevant background information to effectively approach CLBP. The clinical presentation of the patient can significantly aid in the diagnostic process (Table 2). Discogenic pain originating from the anterior column of spine is typically characterized by deep, aching, and burning pain located in the midline of the lower back. Patients often report that their pain intensifies with activities such as sitting, bending forward, and changing position from sitting to standing[13]. Generally, these patients tend to prefer walking over sitting, as they find it challenging to tolerate prolonged periods in a seated position.

As flexion-based movements exert significant amount of stress on the anterior column of spine, a key expectation during physical examination is the presence of pain during such movements. This finding is particularly significant for patients, as it is widely acknowledged that extension-based movements are generally associated with posterior column structures, including the facet joints. Additionally, tenderness during palpation serves as a crucial indicator for clinicians in their diagnostic approach.

Is Imaging Useful for Patients with LBP Related to Discogenic Pain?

While magnetic resonance imaging (MRI) is an essential diagnostic tool for spinal-related pain issues, its utility in CLBP can be limited due to its insufficient diagnostic value. The correlation between MRI findings and patients' symptoms can often be unclear, and internal disc disruptions are not well visualized using this imaging technique. In contrast, discography with contrast material presents a more effective method for diagnosing internal disc disruption.

It is known that innervation in endplates is more extensive in symptomatic patients. Increased innervation is particularly expected in painful discs exhibiting annular fissures and radial tears. Current evidence indicates that endplates with pathologies have significantly higher nerve densities than those without pathologies. Vertebral endplate signal changes have been identified as a potential MRI finding in patients with non-specific LBP, with a median prevalence of 43%[14].

Table 2. Important clinical presentation of anterior column pain
Midline low back pain (deep, aching and burning)
Pain worsens with sitting, bending forward, changing position
Patient prefers walking around rather than sitting in a position long time
Tenderness on palpation and percussion
Pain worsens with flexion

Unfortunately, endplate pathologies can be undetectable on MRI in the majority of the cases[15]. Therefore, MRI findings have limited utility in CLBP patients with endplate pathologies.

In contrast to the limited diagnostic value of MRI for endplate pathologies, vertebral bone marrow lesions can be identified as MC on MRI. MC exhibit high specificity for DLBP[16]. Since MC prevalence is high in CLBP patients and back pain severity can correlate with MC lesion size, the high specifity of MRI findings may have importance in the clinical practice[16]. Therefore, the presence of high-intensity zones and MC on MRI serves as an indicator of discogenic pathology associated with discogenic pain.

In a study analyzing lumbar radiographs of 2,819 participants, de Schepper et al.[9] found a significant association between disc space narrowing at two or more levels and LBP. Their findings indicated that disc space narrowing was more closely linked to LBP than osteophytes and other radiographic features, particularly after excluding the L5-S1 level.

The Role of SVN in CLBP

A thorough understanding of the SVN's anatomy is crucial for understanding its role in CLBP (Figure 1). The initial understanding of this topic began to take shape after the research conducted by Bogduk[17] and Bogduk et al.[18], which included microdissection and histological studies in the early 1980s. In these studies, they proposed the possibility of dual innervation of the intervertebral disc by both somatic and sympathetic systems and provided detailed anatomical description of the rami communicans. Over time, the concept of dual innervation by the somatic nervous system and the sympathetic nervous system has gained wide acceptance[19]. Then, this understanding helps explain how diffuse LBP can trigger sympathetic pain. The SVN has a multilevel origin, the primary branch composed by from the subjacent intervertebral level, the smaller branches composed from the level below and above, allowing it to extend over three segments. This complex structure of SVN, combined with its sympathetic component and multi-level origin, likely contributes to the diffuse and poorly localized nature of discogenic pain associated with the SVN.

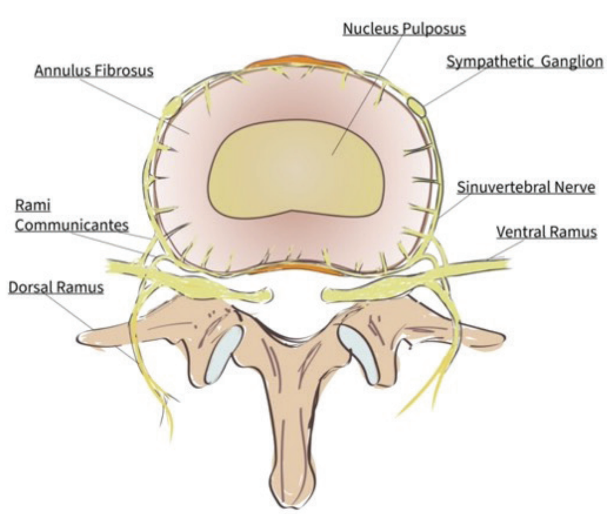

Figure 1. Illustrates the anatomy of the sinuvertebral nerve and the innervation of the intervertebral disc

Similarly, understanding the innervation of the annulus is essential for comprehending the SVN ‘s role in discogenic pain. Nociceptive signals from the anterior and lateral annuli are clearly transmitted via the sympathetic pathway[20]. However, the pathways for nociceptive signals from the posterior annuli are still debated. These nociceptive pathways may involve both the somatic and sympathetic systems or could rely entirely on the sympathetic pathway via rami communicans fibers[20].

The sympathetic components are the SVNs and the rami communicantes. These nerves provide innervation to many of the key anatomical structures associated with diffuse CLBP, such as the dorsal longitudinal ligament, intervertebral discs, and the ventral portion of the dura mater[19]. The notable feature of this nerve is that the SVN cannot directly reach a somatic element at each lumbar spine level. Instead, it transmits pain impulses via the rami communicantes, which are sympathetic fibers, and connects to the L2 spinal ganglion[19]. As a result, pain originating from the L3, L4, and L5 levels is transmitted by the SVN s, which relay signals to the CNS through the L2 spinal ganglion. This raises discussions regarding the potential advantages of infiltrating the L2 spinal ganglia as a treatment option for patients with CLBP.

Top of FormBottom of FormStudies Investigated Origin of SVN

While the precise origin of the SVN remains a topic of debate, recent studies suggest that it consists of branches from both somatic and autonomic roots. Specifically, the somatic roots originate from the ventral ramus, while the autonomic roots arise from the gray ramus, collectively forming the SVN[21].

A recent anatomical study provides a detailed anatomical understanding of the SVNs. In this study, Zhao et al.[21] examined 10 embalmed human cadavers, identifying a total of 450 SVNs across 100 lumbar intervertebral foramina. Their findings categorized the SVN s into two groups: SVN accessory (or deputy) branches and SVN main (or trunk) branches. The SVN main trunks were mainly (97.00%) present in the intervertebral foramina. The initial segment of the SVN was located along the posterior-lateral edge of the disc, and the main trunks originated from two primary sources: 44.2% from the gray ramus communicans and 55.8% from the anterior surface of the spinal ganglia.

In an animal study, Nakamura et al.[22] examined the intervertebral discs following the resection of sympathetic trunks, both unilaterally and bilaterally, at various levels in forty-five rats. Their primary focus was on the posterior aspect of the lumbar intervertebral discs, as disk lesions typically occur in this region. The results revealed distinct differences between unilateral and bilateral resections. In cases of total bilateral resection of the sympathetic trunks, the neural network in the posterior portion of the intervertebral discs was found to be absent. Conversely, a slight decrease in innervation was noted in instances of bilateral single-level resection or unilateral multisegmental resection. Thus, the researchers concluded that the innervation of the posterior lumbar intervertebral discs is supplied by multi-segmental and bilateral sympathetic nerves.

In a study that investigates the anatomy of the SVN to enhance understanding of its potential role in lumbar discogenic diffuse pain[23]. Quinones et al.[23] conducted on six lumbar blocks from donors, the dissection revealed the SVN's origin from somatic and sympathetic branches of the rami communicantes. Out of 48 intervertebral canals examined, 43 SVNs were evaluable, with some levels exhibiting two SVNs. The SVN displayed various patterns of course in the vertebral canal, primarily an ascending branch, and had connections with adjacent SVNs in several cases. The findings suggest that a thorough understanding of SVN anatomy could lead to improved treatments for DLBP, with recommendations to block the SVN at the inferior vertebral notch of adjacent segments.

Studies Investigated Effects of SVN Blocks in DLBP Diagnosis and Management

Wang et al.[24] conducted a study that aimed to assess the effectiveness of SVN blocks in diagnosing DLBP, data from 48 patients with suspected discogenic pain at L4/5 were analyzed. Twenty-four patients received discoblocks (intradiscal injection of 1 mL 0.5% lidocaine), while another 24 received SVN blocks. Patients who responded positively underwent percutaneous endoscopic radiofrequency thermal annuloplasty. Both groups showed similar improvements in visual analogue scale (VAS) and Oswestry Disability Index (ODI) scores at all time points, with significant improvements post-surgery. The study concluded that SVN block is as effective as discoblock for diagnosis and warrants further research.

In a study aimed at assessing the sensitivity and target specificity of SVN block (SVNB) for diagnosing lumbar discogenic pain, and comparing it to the gold standard of discography[25], Schliessbach et al.[25] concluded that SVNB cannot yet replace discography. However, the results suggest potential for future improvements in target specificity. Success of SVNB was defined by Schliessbach et al.[25] as at least 80% pain reduction or significant relief of physical limitations. They conducted the study with fifteen patients who had positive discography results and underwent SVNB, finding that the sensitivity of SVNB was 73.3%, while its target specificity was lower, at 40%.

In a retrospective study, Liu et al.[26] investigated the diagnostic and clinical efficacy of SVNB for the management of DLBP. Their research involved 32 patients with DLBP and tracked their outcomes over time. The improvement rates in VAS scores were 56.52% at 3 days, 54.34% at 7 days, 38.61% at 1 month, and 34.26% at 3 months following SVNB. This study demonstrated that SVNB is a rapid and cost-effective minimally invasive treatment. ODI scores were also improved in the study patients. These findings indicated that SVNB not only assists in diagnosis but also provides short-term pain relief and improves physical function in patients with DLBP.

CONCLUSION

The review emphasizes that understanding the anatomy and role of the SVN is critical for diagnosing and managing CLBP related to discogenic pathology. The involvement of sympathetic components like the SVN and rami communicantes, and their role in transmitting diffuse, poorly localized pain, underlines the potential of SVNB as a diagnostic tool. Studies indicate that while the effectiveness of SVN blocks is comparable to other methods such as discoblock (intradiscal injections), their specificity is still limited, warranting further investigation and refinement for better clinical application in diagnosing DLBP. By focusing on the distinct roles of the SVN nerves, novel treatment strategies such as nerve blocks may offer potential improvements in pain management and patient outcomes.

Footnote

Authorship Contributions

Concept: B.C., A.C., Design: B.C., A.C., Analysis or Interpretation: B.C., Literature Search: B.C., Writing: B.C.,

Conflict of Interest: The authors have no conflicts of interest to declare.

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ARTIFICIAL INTELLIGENCE-POWERED SPINE SURGERY: A SYSTEMATIC REVIEW OF CURRENT TRENDS AND FUTURE PROSPECTS

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ABSTRACT

Artificial intelligence (AI) in spine surgery is a revolutionary technology that can significantly assist clinicians in more accurate and efficient patient diagnosis, treatment planning, and outcome prediction. This review examines the recent applications of AI technologies in spine surgery, which are becoming increasingly common in our daily practice and are expected to play an important role in the future. For this purpose, the PubMed electronic database was searched between September 2023 and September 2024 using keywords related to spinal pathologies, anatomical structures, diagnostic methods, and AI applications. A total of 217 articles met the inclusion criteria for the study. The country of study, anatomical region, data size, spinal pathologies, and purpose of the study were evaluated from the data. In conclusion, the application of AI in spine surgery is revolutionizing the field by increasing diagnostic accuracy, surgical precision, and postoperative care. As the technology continues to evolve, the integration of AI into spine surgery can further improve patient outcomes and surgical efficiency, making AI an essential component of modern surgical practice.

Keywords: Artificial intelligence, deep learning, machine learning, spine, surgery

INTRODUCTION

Artificial intelligence (AI) originated in the 1950s with Alan Turing's query, "Can machines think?". Since then, AI has found widespread application in the medical field and has been the focus of extensive research. AI is employed in various medical domains, including assessing patient risk factors, enhancing the accuracy and efficiency of medical imaging diagnosis, creating new chemical compounds for treatment, and optimizing hospital operations[1]. The utilisation of AI enables physicians to reduce the time required for diagnosis, thereby facilitating more accurate conclusions. By analysing the data entered, it can identify relationships that are not perceptible to the physician through visual means. It is also important to note that the objective of this technology is not to replace the physician. Conversely, it serves to reinforce the physician's capabilities and enhance the efficiency of their work[2]. In spine surgery, AI is considered a revolutionary technology that can significantly assist clinicians in making more precise and efficient patient diagnoses, treatment planning, and outcome prediction[3-7].

AI is a branch of computer science that aims to equip computer systems with advanced intelligence using algorithms to simulate reasoning and decision-making[8]. Machine learning (ML) and deep learning (DL) are subfields of AI. ML uses statistical techniques to make predictions and can quickly identify crucial imaging features necessary for diagnosis that may elude the average clinician[9].

On the other hand, DL is a subset of ML that employs artificial neural networks with multiple layers to analyze diverse data types[10]. The increasing global prevalence of spine-related conditions and the escalating healthcare costs call for a transformative approach[11]. Integrating AI technologies into spine surgery represents a significant advancement in this field and can positively impact diagnostic accuracy, treatment efficiency, and postoperative outcomes. Applications of AI technologies in spine surgery, which are becoming increasingly prevalent in our daily practice and are expected to continue playing a pivotal role. The rapid advancement of AI technology presents a challenge for clinicians attempting to keep pace with developments in this field. This review aims to provide a summary of spine AI studies conducted over the past year.

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MATERIALS AND METHODS

Search Strategies

In a systematic review following the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (Figure 1)[12], we searched the PubMed electronic database between September 2023 and September 2024 using keywords related to spine pathologies, anatomical structures, diagnostic methods, and AI applications (Table 1). A search of the formula presented in the table, conducted by entering "Advanced" in the PubMed database, yielded 577 studies. Six articles in the publication phase or withdrawn were excluded, along with 40 articles not in English or with inaccessible full texts. Finally, 217 articles met the inclusion criteria for the study.

Exclusion Criteria

- Animal experiments, cadaver studies, microscopic and biochemical studies
- Studies on technical issues, such as improving radiological imaging and removing artifacts
- Studies to distinguish the brands and materials of the materials used as implants
- Studies related to rheumatology and physical therapy and rehabilitation applications
- Studies on non-vertebral anatomical structures and pathologies in the cervical, thoracic, and lumbar regions
- Studies that include other bone tissues (skull, pelvis, ribs, etc.) along with the spine in radiologic imaging
- Systematic review and meta-analysis studies

Data Collection and Analysis

The following main headings were identified, and data were obtained from the 217 articles included in the study.

- Country of study
- Anatomical region: Categorized into three main categories: Cervical, thoracic, and lumbosacral (Given the absence of a single study on the sacral region in the 217 articles under review, the lumbosacral region was evaluated as a single anatomical area). However, studies involve two different anatomical regions or the whole spine
- Size of the data used in the study: Number of patients or radiologic images/sections (n<100, 101-1000, n>1000)

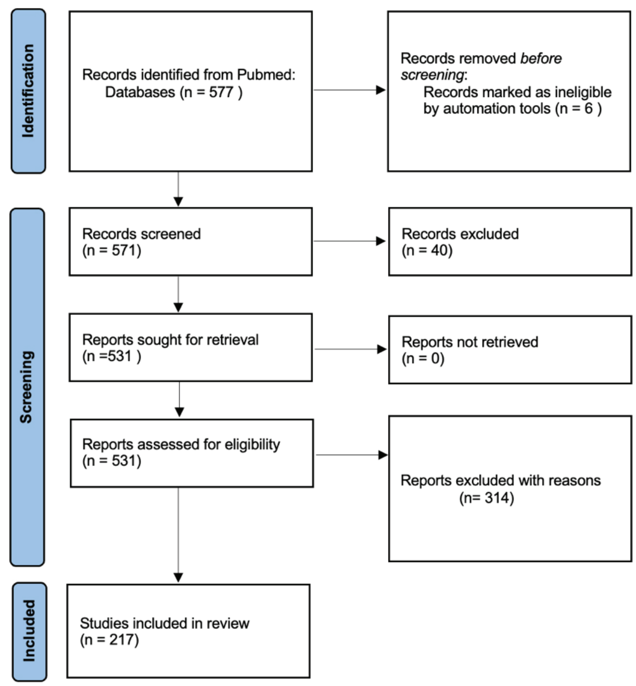

Figure 1. Flow chart of PRISMA diagram
PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses

Table 1. Search formula used in searching PubMed database (modified from Constant et al.)(8)

(("Spine" [MeSH] OR "back" [MeSH] OR "Zygapophyseal Joint" [MeSH] OR "Spinal Diseases" [MeSH] OR "Sciatica" [MeSH] or "Spinal Injuries" [MeSH] OR "Laminectomy" [MeSH] OR "Cementoplasty" [MeSH] OR "Diskectomy" [MeSH] OR "Intervertebral Disc Chemolysis" [MeSH] OR "Laminoplasty" [MeSH] OR "Osteotomy" [MeSH] OR "Spinal Fusion" [MeSH] OR "Spinal Puncture" [MeSH] OR "Foraminotomy" [MeSH] OR "Neuroendoscopy" [MeSH] OR "Total Disc Replacement" [MeSH] OR "Pedicle Screws" [MeSH] OR Spine [tiab] OR Spina* [tiab] OR "degenerative disc" [tiab] OR "vertebr*" [tiab] OR "scoliosis" [tiab] OR "disc degeneration" [tiab] OR "Disc Degradation" [tiab] OR "disc disease" [tiab] OR "intervertebral disc" [tiab])) AND ((("Machine Learning" [MeSH] OR "Neural Networks, Computer" [MeSH] OR "naive bayes" [tiab] OR "bayesian learning" [tiab] OR "neural network*" [tiab] OR "random forest" [tiab] OR "deep learning" [tiab] OR "machine prediction" [tiab] OR "machine intelligence" [tiab] OR "generative adversarial networks" [tiab] OR "Hierarchical Learning" [tiab] OR "computer vision" [tiab] OR "computational intelligence" [tiab] OR "computational learning" [tiab] OR "computer reasoning" [tiab] OR "machine learning" [tiab] OR "reinforcement learning" [tiab] OR "convolutional network*" [tiab] OR "artificial intelligence" [tiab] OR "Self Organizing MAP" [tiab] OR "Self-Organizing MAP" [tiab] OR "AutoEncoder" [tiab] OR "CNN" [tiab] OR "GAN" [tiab] OR "GANN" [tiab])) OR (("convolute" [All Fields] OR "convoluted" [All Fields] OR "convolutes" [All Fields] OR "convoluting" [All Fields] OR "convolution" [All Fields] OR "convolutional" [All Fields] OR "convolutions" [All Fields] OR "convolutive" [All Fields]) AND ("neural networks, computer" [MeSH Terms] OR ("neural" [All Fields] AND "networks" [All Fields] AND "computer" [All Fields]) OR "computer neural networks" [All Fields] OR ("neural" [All Fields] AND "network" [All Fields]) OR "neural network" [All Fields]))) AND (("Diagnostic Imaging" [MeSH] OR "Image Processing, Computer-Assisted" [MeSH] OR "Imaging" OR "Radiograph*" OR "x?ray" OR "Tomograph*" OR "Magnetic Resonance" OR "MR?image*" OR "MRI" OR "MRA" [tiab] OR "CT?Scan*" OR "Ultrasonograph*" OR "Ultrasound*" OR "PET?Scan" OR "c-arm" OR "fluoroscop*" OR "arthrogram*" OR "arthrograph*" OR "venogram*" OR "venograph*" OR "cone?beam CT" OR "image-guided adaptive radiation therapy" OR "IGART" [tiab])) AND (("2023/09/01" [Date-Publication]: "2024/09/24" [Date-Publication])) NOT ((systematic review [pt] OR review [pt]))

• Spinal pathologies
• Degenerative: Facet joint pathologies, disc pathologies, narrow canal, spondylosis, spondylolisthesis, and myelopathy are included in this group
• Trauma: Fractures, spinal cord injuries. Separation of old and new fractures is also included in this group
• Tumor: Primary or metastatic tumors
• Infection
• Deformity: Scoliosis, sagittal-coronal balance disorders, adult spinal deformity
• Osteoporosis
• Other pathologies: Ossified posterior longitudinal ligament, tethered spinal cord syndrome, etc.
• Purpose of the study
• Diagnosis
•Clinical decision making
•Surgical planning
•Making prognostic predictions for the future during a treatment or the natural course of any disease, risk analysis

RESULTS

Country of Study

Two hundred seventeen studies were distributed across 29 countries. China alone accounted for 38% of all studies. China, the US, and Korea conducted 61% of all studies last year (Figure 2). The countries with the most studies in medicine are the US, China, and the UK[12]. China seems to have been at the forefront of AI studies on spine surgery in the last year.

Anatomical Region

Considering the anatomical regions where the studies were performed, the lumbosacral spine had the most data followed by cervical and thoracic regions. When studies involving more than one region are analysed, thoracolumbar (28.11%) and whole spine (24.88%) have similar rates (Figure 3).

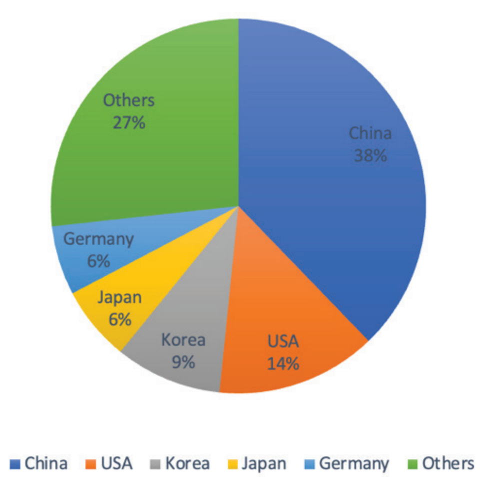

Figure 2. Distribution of countries where studies included in the review were conducted

Data Size

Among the three headings where data size, an essential parameter in AI applications, is collected, n>1000 is the most common (81.56%) (Figure 4).

Spinal Pathologies

Degenerative (30%), deformity (27%), and trauma (26%) are in the top three in close proportions. Although osteoporosis is not an area of direct interest in spine surgery, it has been analysed under a separate heading due to its high incidence and the fractures it causes. In the last year, 7.83% of the AI studies related to the spine were related to osteoporosis. In line with epidemiological data, tumours, infections and other spinal pathologies are less common in all studies (9.2%) (Figure 5).

Purpose of The Study

In terms of the intended use of the AI algorithm in the clinic, diagnosis represents the primary application, accounting for 74.65% of all cases. This is followed by prognosis prediction (16.59%) and surgical planning (5.99%). Decision-making studies represent the lowest percentage of applications at 2.76% (Figure 6).

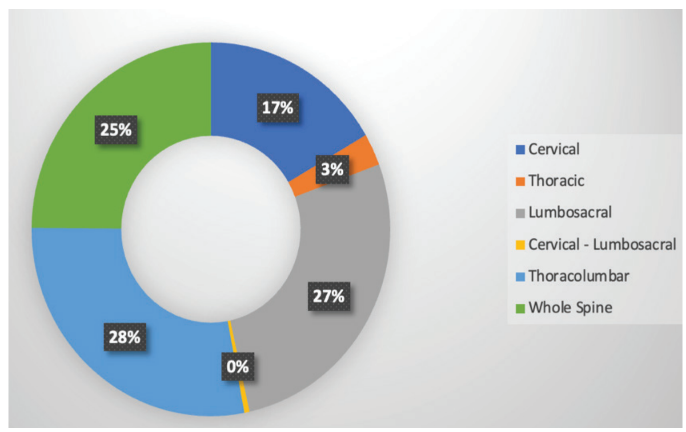

Figure 3. Distribution of anatomic regions

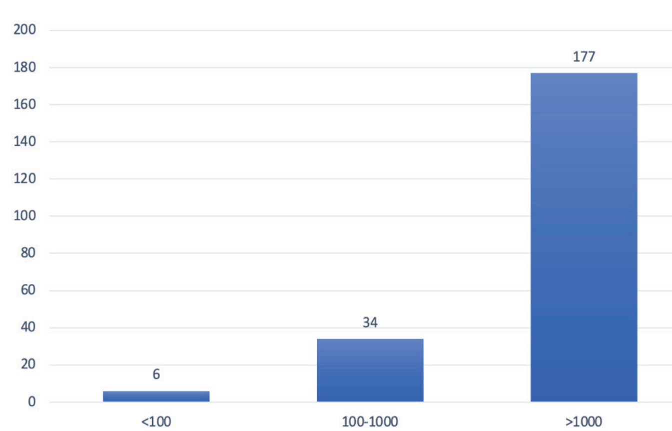

Figure 4. Distribution of data size

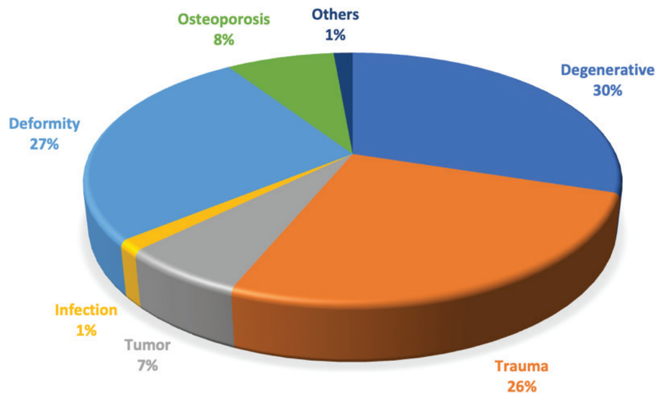

Figure 5. Distribution of spine pathologies

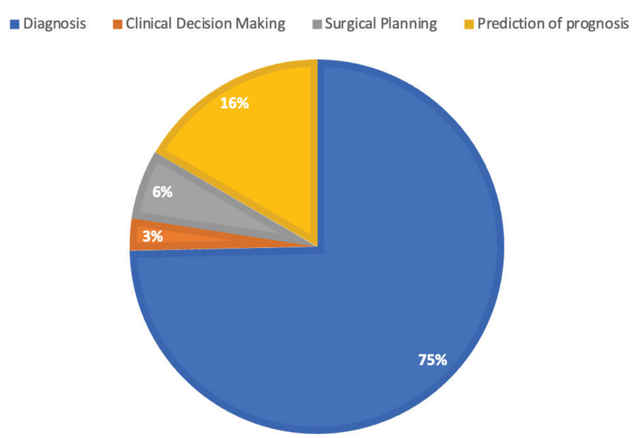

Figure 6. Distribution of the main purpose of the study

DISCUSSION

The article provides a comprehensive overview of the applications of AI in spinal surgery, focusing on the past year. The review draws on data from PubMed, a medical database, and proposes the potential for more extensive research utilizing scientific databases. The prevalence of Chinese studies in this field aligns with China's aim to become a global leader in AI by 2030[13]. The limited involvement of other countries underscores the need for increased investment in AI, particularly in densely populated countries, to enhance the quality and quantity of data and findings.

The study highlights the prominence of the lumbosacral region (27%) when considering anatomical locations, reflecting epidemiological trends. Research on deformities or tumors typically evaluates the entire vertebra as a whole. However, the thoracolumbar region is prominently featured in studies related to compression fractures and osteoporosis (28%). Given the paucity of research examining the sacral region as a discrete entity, it was assessed in conjunction with the lumbosacral region. Nevertheless, in the future, sacral region pathologies may be evaluated under a distinct heading or may be the subject of a standalone study.

In AI, the volume of data used to develop algorithms is a crucial factor influencing the success of results[14]. The model's capacity to capture complex data relationships and variations significantly improves with exposure to a broader array of samples, leading to higher prediction accuracy[15]. More data not only yields more precise results but also aids clinicians and saves time[16]. Nevertheless, it is imperative to emphasize that merely increasing data input is insufficient; the quality of data input is equally critical for application success[17]. Most studies in our review involved datasets with over 1000 entries (81.5%), and studies with even more significant data inputs are anticipated to bolster confidence in AI. The field of spinal surgery encompasses a wide array of diseases, making it more practical to categorize them rather than study each individually. This study classified diseases into degenerative, trauma, tumor, infection, deformity, and osteoporosis, with a small percentage falling under the "other" category. Degenerative diseases, trauma, and deformity disorders comprised the majority (93%) of the studies. It is anticipated that there will be an increase in the number of studies and meta-analyses for each category and subgroup. Additionally, using AI applications will be crucial for identifying less common pathologies such as infections and tumors.

Since its inception in the medical field, AI has developed algorithms focused on diagnostic accuracy, yielding similar results to those observed in this review. While 75% of recent studies have concentrated on recognition applications, there has also been a rise in research on crucial aspects such as surgical planning, prognostication, and decision-making in clinical scenarios. Surgical planning, especially in deformity surgery, is essential, and systems designed for this purpose utilize real-time imaging and intelligent operation planning to guide surgeons, ultimately improving surgical outcomes and reducing intraoperative radiation exposure[18]. Incorporating AI into surgical interventions enhances accuracy and minimizes human error by detecting and rectifying potential errors during procedures[19].

The utilisation of AI technologies has markedly improved patient safety in the field of spine surgery. A study has demonstrated that the integration of ML can mitigate the risks associated with surgical procedures by optimising patient selection and preoperative planning, thereby reducing complications and enhancing overall outcomes[20]. The use of AI for risk stratification has been demonstrated to be effective, with studies demonstrating that predictive models can achieve high accuracy rates. For example, an 87.6% prediction accuracy for perioperative complications in spinal deformity surgeries has been reported. This capability allows for more informed decision-making and tailored surgical approaches, which ultimately lead to improved patient safety[21].

The clinical applications of AI in improving imaging and predictive pattern detection are of crucial importance for effective surgical decision-making in complex cases. The ability of AI to analyse vast datasets and identify patterns that may not be immediately apparent to human practitioners represents a significant advancement in surgical practice[22]. ML models can accurately predict the outcomes of lumbar spinal fusion surgeries, thereby facilitating the optimisation of surgical strategies and postoperative care[23]. Furthermore, personalized discussions with patients in the preoperative phase can make the surgeon-patient relationship more reliable by providing quantitative data on expected benefits and risks[24-27]. Specific studies have focused on various surgical procedures and their associated complications, employing ML models to predict hospital readmissions and artificial neural networks to anticipate complications following posterior lumbar spine fusion[28,29].

AI can potentially enhance clinical decision-making and may even supplant human judgment in certain healthcare functions[30]. However, it also facilitates shared decision-making between clinicians, patients, and their families[31]. On the other hand, the least common use of AI in spinal surgery is currently decision-making, but this is expected to change with more studies in the future.

Despite the promising advancements in AI, its application and adoption in spine surgery present several challenges. Ethical considerations regarding patient data privacy, the necessity for rigorous clinical studies to validate AI applications, and the integration of AI tools into existing clinical workflows are crucial areas for ongoing research and discussion[32]. Additionally, there is a need to establish standardized protocols and guidelines for AI implementation in clinical practice to ensure improved surgical precision and patient outcomes[6].

CONCLUSION

In conclusion, the application of AI in spine surgery is revolutionising the field by increasing diagnostic accuracy, improving surgical precision and optimising postoperative care. As technology continues to evolve, the integration of AI into spine surgery promises to further improve patient outcomes and operational efficiency, making it an essential component of modern surgical practice. This will require surgeons to collaborate with AI practitioners and data scientists, and universities and research centres to adopt a multidisciplinary approach that includes departments in AI and computer science.

Footnote

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