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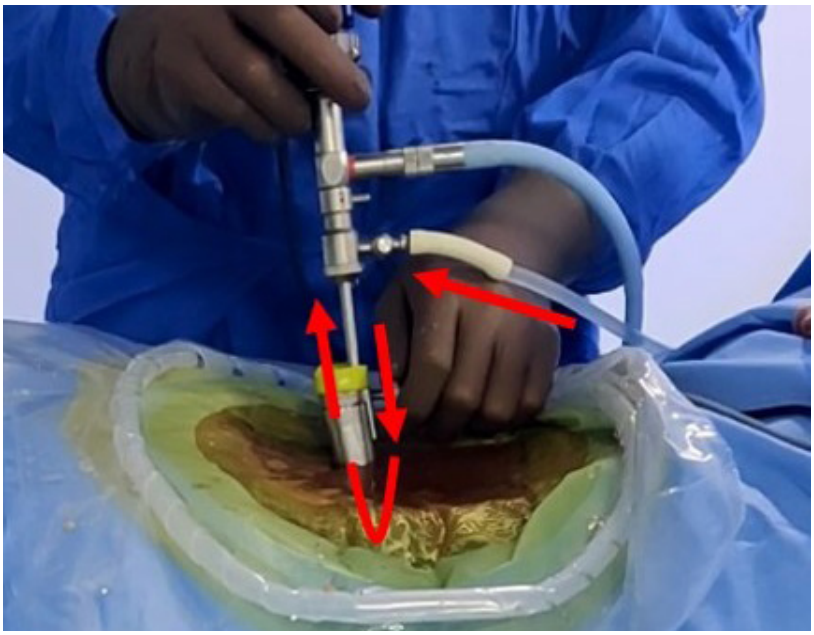
Uniportal Endoscopic Approach to the Degenerative Spine



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Aims and Scope

Journal of Minimally Invasive Spine Surgery & Technique (JMISST) is the official journal of the Korean Minimally Invasive Spine Surgery Society (KOMISS), Minimally Invasive Spine Surgeons Association of Bharat (MISSAB), Taiwan Society of Minimally Invasive Spine Surgery (TSMISS), Taiwan Society of Endoscopic Spine Society (TSESS), Brazilian Minimally Invasive Spine Surgery Society (BRAMISS), Latinamerican Endoscopic Spine Surgery Society (LESSS), Spanish Endoscopic and Percutaneous Spine Surgery Society (SECPEC), and Malaysia Society of Endoscopic Spine Surgery (MSESS) for the publication of research results about minimally invasive spinal surgery (MISS). JMISST will consider submissions in areas of endoscopic spinal surgery, minimally invasive procedure for degenerative spine disease, pain intervention, minimally invasive surgery for spinal fusion or spine trauma, neuroscience, neurology, molecular biology and biomechanics etc. JMISST provides spine physicians and researchers with peer-reviewed articles on minimally invasive spine surgery to improve patient treatment, education, clinical or experimental research, and professionalism. In particular, minimally invasive spine surgery, including endoscopic spinal surgery, will be the most important field in the future spinal treatment. JMISST is the only journal in the world that is currently focused on minimally invasive spine surgery. We aim to lead the field of minimally invasive spine surgery to be developed in the future, and will contribute to providing a happy life for humans based on academic development.

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Editorial

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The Usefulness and Advantages of Uniportal Fully Endoscopic Spinal Surgery for Various Lumbosacral Pathologies

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This special issue explores various pathologies of challenging lumbosacral lesions through the use of the uniportal endoscopic technique. Our goal is to discuss approaches and methods that improve our understanding of these pathologies and contribute to successful surgical outcomes. I would like to extend my sincere thanks to Dr. Koichi Sairyo and Dr. Ohara Yoko from Japan, Dr. Kuo-Tai Chen and Dr. Se-Yi Chen from Taiwan, and Dr. Dong-chan Lee and Dr. Jun-seok Bae from Korea. Their role as editors has been crucial in ensuring that this special issue presents excellent papers on fully endoscopic spinal surgery.

Lumbosacral structures, including those in the lower lumbar region, are important structures that support the entire body weight during upright walking in humans. As degenerative changes progress, common conditions such as disc herniation and spinal stenosis can lead to neurological symptoms [1,2].

The minimally invasive approach to the lumbosacral region presents significant challenges due to anatomical complexities. Factors including the iliac crest, hypertrophy of the L5 transverse process, and Bertolotti syndrome contribute to the complexity of these surgical procedures [3–5].

In cases of lumbosacral lesions, particularly at the L5–S1 level, the transforaminal approach often presents challenges, leading to a preference for the interlaminar approach, which is generally considered easier [6,7]. However, the transforaminal approach can be effective for conditions such as far lateral disc herniation, foraminal stenosis, and far-out syndrome [2,3].

Successfully performing the fully endoscopic transforaminal approach necessitates a comprehensive understanding of lumbosacral anatomy and the use of various techniques to facilitate the surgical procedure.

The transforaminal approach provides several advantages, especially in elderly patients for whom surgery under local anesthesia is possible [3,8]. This method bypasses the spinal canal, which helps minimize the formation of epidural scar tissue and reduces the risk of dural tears. However, careful consideration is required due to the potential for frequent irritation of the exiting nerve root, which can be attributed to the difficulty of access.

Uniportal fully endoscopic spinal surgery, which involves using a single portal for endoscope insertion and performing all procedures within the endoscope, offers a more minimally invasive

approach than biportal endoscopic surgery. The latter requires additional working space to insert both the endoscope and surgical instruments. However, the uniportal method is limited to a single surgical direction, which can present challenges with incorrect targeting. Additionally, the use of instruments is confined to passage through the endoscope, requiring a high level of skill and proficiency [3,9,10].

Nevertheless, once the learning curve is overcome, this approach has the advantage of preserving normal structures while selectively removing pathological areas, surpassing many other surgical techniques in this regard [11].

This special issue presents articles on various treatment methods for lumbosacral pathologies, which are anatomically challenging to access, using uniportal fully endoscopic surgery. We hope that these foundations will lead to further advancements in the field.

NOTES

Conflict of Interest

CIJ, a member of the Editorial Board of Journal of Minimally Invasive Spine Surgery & Technique, is the corresponding author of this article. However, he played no role whatsoever in the editorial evaluation of this article or the decision to publish it. Author has no conflict of interest to declare.

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Review Article

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Surgical Options for Bertolotti Syndrome

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This article provides a comprehensive examination of Bertolotti syndrome (BS), a disorder characterized by back pain due to a lumbosacral transitional vertebra, to facilitate surgical decision-making by exploring various surgical options, including the innovative approach of endoscopic spine surgery. A review of existing literature and studies on BS published until December 2023 was undertaken, utilizing databases such as PubMed and Google Scholar to identify relevant information. The review offers an integrated overview of the essential knowledge of BS and a comprehensive range of surgical treatments. Symptomatic BS can manifest as pain originating from pseudoarticulation and the facet joints, discs, adjacent segments, and the L5 root, indicating a diverse distribution of pain sources. Furthermore, various surgical strategies are tailored to the specific origin of pain, including pseudoarticulation resection, transverse processectomy, decompression, nerve root decompression, fusion, and endoscopic spine surgery. For individuals with BS contemplating surgical solutions, performing a detailed assessment of symptoms and physical evaluations is imperative to accurately identify the origin of the pain. The choice of a surgical strategy must be meticulously customized according to the identified source of pain, guaranteeing a tailored and efficacious treatment for each patient.

Key Words: Bertolotti syndrome, Lumbosacral transitional vertebrae, Pseudoarticulation, Surgical options, Endoscopic spine surgery

INTRODUCTION

Bertolotti syndrome (BS) is defined as low back pain arising from the presence of a lumbosacral transitional vertebra (LSTV). The LSTV possesses an extensive transverse process (TP) that is pseudoarticulated or fused with the sacrum or ilium. When the TP of the lumbar vertebra enlarges, it can cause disc-induced pain and restrict mobility [1].

The clinical symptoms of BS are complex because they can range from being entirely asymptomatic to exhibiting numerous nonspecific symptoms. Complete asymptomatic cases are relatively rare, occurring in 13% of cases, and symptoms can arise from scoliosis joint arthropathy or strain in muscles such as the quadratus lumborum and iliopsoas [2]. Additionally, neurological symptoms may occur due to nerve compression from disc pressure caused by the deformation of the transitional vertebra [3]. Symptoms associated with each of these causes require different treatments.

The diagnosis of BS is made through clinical symptoms and radiographic examinations, identifying the syndrome as caused by LSTV. According to the literature, the prevalence of this syndrome widely varies, between 4%–35%, and its similarity to other diseases presenting with lower back pain may result in misdiagnosis. Moreover, the clinical symptoms of BS often do not correlate with radiographic findings, complicating radiological differentiation [4].

The optimal treatment method for BS is still under investigation and remains a topic of debate. Initially, treatment includes

conservative management, local injections, radiofrequency ablation, and surgery [5]. Conservative treatments, including physical therapy and pharmacological treatment with nonsteroidal anti-inflammatory drugs, are recommended at the outset. If conservative treatment fails to provide relief, further interventions such as local injections, steroid injections, and surgical resection or fusion may be considered. Although many treatable approaches for BS exist, standardized treatment protocols and management strategies remain lacking. Therefore, identifying the mechanism and cause of pain is crucial in treating BS.

This review addresses the overall understanding of LSTV and the current surgical treatments. It focuses on establishing strategies for surgical intervention tailored to the various pain patterns that can arise from LSTV, presenting various methods to this end. This review highlights the importance of compiling all reported endoscopic surgeries for LSTV that consider their advancements.

PREVALENCE

LSTV possess a broad estimated prevalence range in the general population, from 4% to 36%, with an overall average of 12.3% [6]. The prevalence of LSTV is generally higher in men than in women, with some studies indicating it to be at least twice as high. Among the forms of LSTV, sacralization of L5 is more common in men, whereas accessory L5–S1 articulation and S1 lumbar articulation are more frequent in women [7]. The occurrence of LSTV in families with an increased incidence suggests a genetic factor, with the *HOX10/HOX11* genes impacting the axial patterning of the lumbar and sacral vertebrae. Mutations in these genes could play a role in the formation of LSTV [8].

Although LSTV has a high prevalence in the overall population, most cases are asymptomatic, and whether LSTV is truly a cause of lower back pain remains controversial. Castellvi posited that the pain derives from abnormalities in the lumbar region, while others have argued that the severity of pain and backache is unrelated to LSTV [9,10]. Tini et al. [11] found no significant difference in the prevalence of LSTV between patients with and without lower back pain, concluding that LSTV may predict LBP. However, the presence of LBP does not necessarily predict the existence of LSTV. This uncertainty regarding the association between lower back pain and LSTV complicates the determination of the actual incidence rate among patients with BS. Quinlan et al. [12], in a study of consecutive magnetic resonance imaging (MRI) scans of 769 patients with lower back pain, found that 11.4% of those under 30 had LSTV, with an average age of 32.5 years among patients with LSTV. Understanding that LSTV affects a considerable proportion of the younger population is important.

PATHOPHYSIOLOGY

The symptoms of BS are nonspecific. Despite ongoing debate over the past century regarding the association between LSTV and lower back pain, numerous studies have pondered how the presence of LSTV can induce lower back pain. Several theories include: (1) pain secondary to arthritic changes of the pathological joint [13]; (2) pain related to accelerated disc degeneration at the level just above the LSTV [14]; (3) contralateral facetogenic pain due to abnormal stress placed on the contralateral facet joint [15]; (4) sacroiliac (SI) joint pain due to abnormal stress loading [16]; (5) impingement of the nerve root at the extraforaminal zone caused by the anomalous joint [17]. Therefore, BS is considered a multifactorial disorder, and its association with lower back pain cannot be simplified to a single pathology.

First, let us examine the anatomical impact of LSTV on our spine. The sacrum, which supports the lower part of the spine, assists in weight distribution toward the SI joint [18]. A decrease in the height of the sacrum significantly reduces the contact surface area between the sacrum and ilium, complicating the weight distribution role of the SI joint [19]. To compensate for the reduced SI joint surface area in some LSTV cases, L5 sacralization may occur in certain instances. The reduced iliolumbar ligament in these patients can arise from decreased lumbar motion due to the pseudoarticulation or fusion of LSTV. The concomitant weakening of the iliolumbar ligament and the reduced movement at LSTV can contribute to the adjacent segment instability commonly experienced by these patients [19]. Consequently, the increased loading on a relatively small sacral surface area by the large L5 TP decreases the movement at the L5–S1 junction and increases the joint mobility above it. This exacerbates disc herniation and facet arthrosis, inducing pain and leading to asymmetry in spinal movement [20].

Furthermore, in cases with LSTV, nerve root impingement has a prevalence of 13%, and up to 70% of patients with this lesion may exhibit symptoms [21]. The incomplete fusion between the L5 TP and the sacral ala and its micromotion can lead to the development of radiculopathy in patients with BS, causing extraforaminal stenosis that leads to nerve root entrapment and radiculopathy in patients with LSTV [22,23].

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CLASSIFICATION OF LSTV

The LSTV was classified into 4 types by Castellvi et al. [14] in 1984, with each type (I–IV) further denoted as "a" (unilateral) or "b" (bilateral) (Figure 1). Type I signifies a TP of L5 with a width of 19 mm or more, either unilateral (Ia) or bilateral (Ib). Type II represents an extended TP that forms a "pseudoarticulation" with the sacral ala (IIa or IIb), indicating incomplete sacralization (from L5) or lumbarization (from S1). The type III classification indicates complete fusion between the TP and the alar, denoting complete sacralization of L5 or lumbarization of S1. Type IV describes a condition where one side is type IIa and the other is type IIIa [14]. Among the Castellvi classifications, type Ia is the most common, with types I and II accounting for approximately 40% of all LSTV occurrences, respectively [24]. However, the reliability of identifying morphological anomalies in the Castellvi classification is not high, with a sensitivity of 76%–84% and an accuracy of 53%– 58%, leading to the proposal of several classifications for BS.

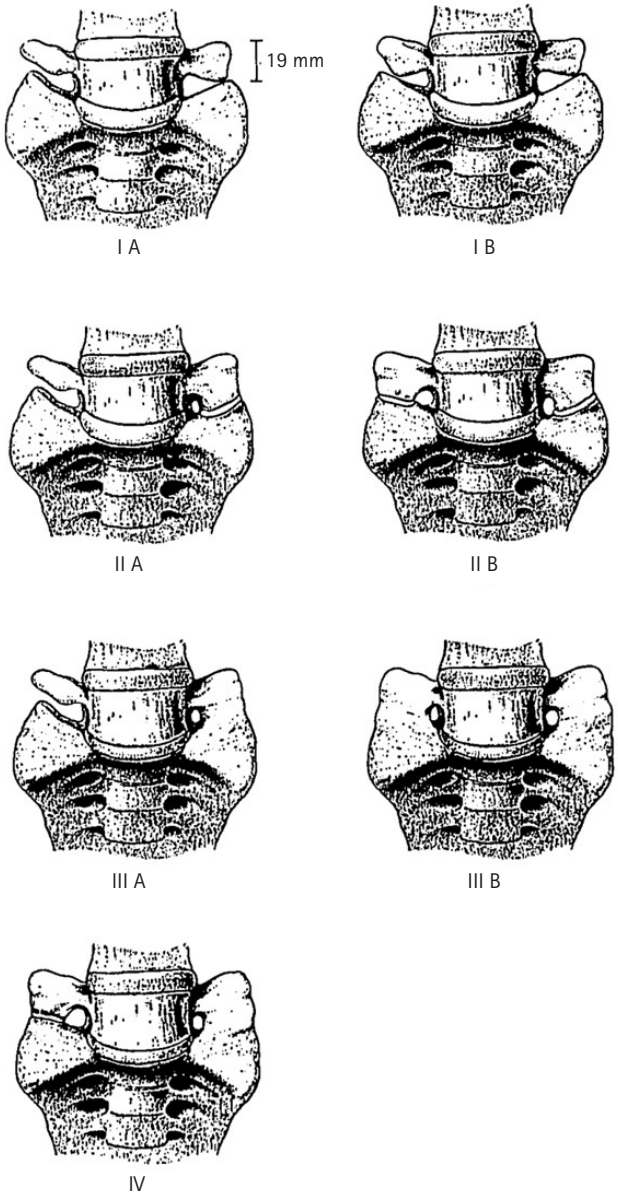

Figure 1. Castellvi classification system of lumbosacral transitional vertebrae. Adapted from Castellvi et al. Spine 1984;9:493-5 [14], with permission of Elsevier.

O'Driscoll et al. [25] used sagittal MRI to classify BS into 4 types based on the morphology of the S1–2 disc and the degree of lumbarization of the S1 segment. This resulted in O'Driscoll classification of sacral morphology: type 1 with no disc material between S1 and S2; type 2 with a small disc that does not extend the anteroposterior (AP) diameter of the sacrum; type 3 with a well-formed disc extending the entire sacral AP diameter; and type 4, which has the features of type 3; nevertheless, it also includes squaring of the upper sacral border. A correlation was found between type 4 S1–2 disc and types III, VI in the Castellvi classification.

The Onyiuke Grading Scale, a new grading system, classifies BS into 4 types based on the location, severity, and characteristics of the pain, focusing on clinical symptoms and less on imaging results [26]. Regarding the Jenkins classification, this new description of LSTV anatomy bases itself on the concept of a reduced gap between the TP and the sacrum as the primary cause of BS rather than disc herniation [27].

DIAGNOSIS

1. Simple Radiograph

Traditional radiography is well documented for its utility in diagnosing and classifying LSTV. AP and lateral films allow evaluation of the spine under axial load while requiring minimal time, financial cost, and radiation exposure to the patient. An AP radiograph taken at a 30° cranial angle, known as a Ferguson radiograph, has traditionally been the standard for successfully identifying LSTV. General radiographs of the lumbosacral region demonstrate 76%–84% effectiveness in detecting LSTV. Ferguson radiographs of the lumbosacral region (AP radiographs with a 30° cranial angle) show higher sensitivity in detecting LSTV [28].

2. MRI/Computed Tomography

High-resolution imaging increases the cost and potential

radiation exposure to patients; however, it provides crucial information for accurately examining BS. Computed tomography (CT) and MRI imaging are more accurate in diagnosing and classifying LSTV than conventional radiographs, offering additional diagnostic information on adjacent areas, discs, or neurogenic pathology.

CT scans are advantageous for defining bone structures, osteophytes, and pseudoarticulation of the L5 TP [29]. MRI can have over 80% accuracy in diagnosing BS, with T2-weighted coronal images being most effective in diagnosing lesions known as the "far-out" syndrome, where nerve roots are impinged between the TP of L5 and the sacral alar.

3. Scintigraphy

Beyond standard radiographs, CT, and MRI, bone scintigraphy may help identify potential sources of pain in patients with BS. Abnormal articulations in LSTV can lead to degenerative and metabolic changes, possibly related to the patient's pain. These changes show increased absorption in bone scintigraphy, with significantly increased absorption observed in symptomatic patients with degenerative changes on single-photon emission computed tomography (SPECT) images [30]. Radiography and injections aside, bone scintigraphy tests such as SPECT/CT and positron emission tomography/CT have shown potential in identifying the source of pain in patients with BS.

4. Slit-Beam Digital Radiography System

The slit-beam digital radiography system, a new radiographic method that emits low doses of radiation, provides accurate 3-dimensional (3D) images of spinal anatomy, which is significant for differentiating and classifying BS. It captures upright orthogonal images and reconstructs 3D images of the skeletal structure (specifically the spine and pelvis), which is useful in determining the relationship between anatomical regions and adjacent segments [31,32]. Despite advancements in imaging techniques, diagnosing BS remains challenging. Differential diagnosis for low back pain is extensive, including myofascial pain, SI pain, fractures (including spondylolysis), spondylolisthesis, scoliosis, disc degeneration/herniation, infection, and malignancy [5,12]. This wide range of differential diagnosis can lead to delayed or missed diagnoses.

5. Local Injections

Steroid and anesthetic injections have proven to offer multifaceted benefits to patients with BS, providing marked diagnostic information and pain relief. Local injections can identify the primary source of pain in these patients.

SURGICAL PLANNING CONSIDERATIONS

Conservative treatments include activity modification, pharmacologic therapy, physical therapy, and interventional therapy. Patients with BS should first undergo conservative treatment before proceeding to invasive treatments such as steroid and anesthetic injections and surgical interventions like removal of LSTV pseudoarticulation, decompression, or fusion. Localized injections can identify the primary source of the patient's pain, enabling targeted surgical treatment and preventing total removal. The degree of pain relief following local injections provides valuable information for guiding surgical treatment if the pain resolves. Surgical intervention can be considered when no response is available for conservative treatment.

Pain caused by LSTV can originate from various lesions. Pain may arise directly from the pseudoarticulation itself. However, it can also be due to asymmetric segmental motion between LSTV and the sacrum, exacerbating weight load on the opposite facet joint, leading to facet arthritis as a source of pain, or increased weight load on the adjacent segment above due to reduced segmental motion [33-36]. In cases where discogenic pain exists concurrently at the LSTV level, performing resection of pseudoarticulation alone may not meet expectations for pain improvement or may worsen discogenic pain due to increased intersegmental movement post-resection. Therefore, in cases with accompanying disc pathology or when pain is associated with increased instability and mobility of the segment, fusion, which can provide long-term stability, may be a better choice than resection [37,38]. Surgeons must be aware of all possibilities that the pain source in patients with symptomatic LSTV may be localized to the pseudoarticulation or may reside in various other lesions, and even possibly more significant than the pseudoarticulation itself, and meticulously plan the surgery after verification. Figure 2 presents a diagnostic and therapeutic diagram of symptomatic LSTVs.

SURGICAL OPTIONS

Surgical treatments for BS including resection, nerve root decompression, and fusion using microscopic techniques have been reported by numerous authors. Endoscopic spinal surgery techniques have improved recently, and there have been

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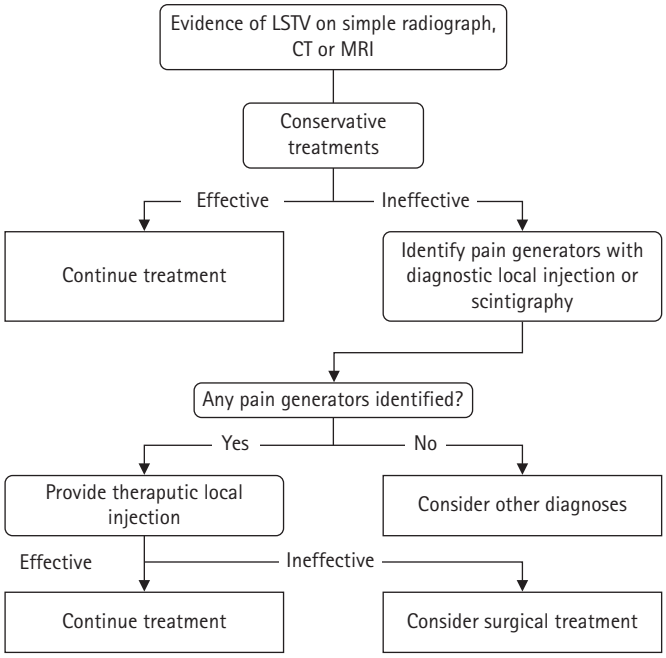

Figure 2. Flow chart for diagnosing and treating symptomatic lumbosacral transitional vertebrae. CT, computed tomography; LSTV, lumbosacral transitional vertebrae; MRI, magnetic resonance imaging.

several reports of surgical attempts to address BS using them. Surgical methods can be categorized as traditional microscopic and endoscopic techniques.

1. Microscopic Surgery

1) Resection

Among the subtypes of LSTV, type II has been reported to have the highest prevalence of low back pain at 73% [38]. According to various reports, the primary candidates for surgical resection of symptomatic BS are those with type II LSTV, which form pseudoarticulations, rather than other types that do not form pseudoarticulations or are already in a state of complete bony union [39,40]. If the pain generator is diagnosed as being localized to the pseudoarticulation, resection becomes the most effective surgical option. The excision of the anomalous connection between the LSTV and the sacrum can mitigate asymmetrical or diminished segmental motion, with potential benefits in alleviating adjacent segment or contralateral facet arthritis to some degree [15]. However, discogenic pain may worsen due to increased segmental motion of the LSTV after resection. Therefore, surgeons must plan the surgery by predicting the clinical outcomes based on the changes in the distribution of mechanical stress around the LSTV before and after resection. In cases accompanied by far-out syndrome, the surgical plan should include root decompression, which can be performed simultaneously with the resection. To prevent misdiagnosis, a diagnostic block of the pseudoarticulation is recommended before surgery [34]. Most authors reporting on the resection of LSTV have performed a preoperative diagnostic block [41]. Nonfusion surgeries reported to date for removing pain originating from pseudoarticulation can be categorized into resection of pseudoarticulation, TP resection, and anterior approach technique.

(1) Pseudoarticulation resection

The resection of the pseudoarticulation technique directly removes the pathological tissue causing pain and is a standard method that can disconnect the mechanical impact on adjacent joints. Using AP fluoroscopic imaging to locate the TPs, sacrum, and articular processes, a 2.5- to 4-cm vertical incision is made approximately 4 cm lateral from the midline, directly above the articular process. The fascia is sharply opened, and muscle/ligament attachments are removed to expose the TP, pseudoarticulation, and sacral alar. High-speed drills are then used to remove the pseudoarticulation. A tubular retractor may be used to minimize tissue damage [40-44], although its use may limit surgical visibility, making the surgery more challenging and possibly leading to inadequate decompression [41]. Care should be taken when selecting the incision site as the iliac crest may obstruct the surgical trajectory, with some authors reporting resection of part of the left posterior iliac crest to access the pseudo articulation [43]. Pseudoarthrectomy can present challenges due to the potentially wide and irregular anatomical shapes, leading to anatomic misorientation within the operative field, which can be particularly challenging for surgeons with less experience in BS resection surgery. This may result in unnecessary resection of normal tissue or insufficient resection of the target lesion. Thus, confirming the most ventrolateral margin of the pseudoarticulation is recommended before beginning resection with high-speed drilling [45]. Navigation for stereotactic localization of the pseudojoint has been reported as a viable complementary method, or repeated verification with a C-arm is recommended if navigation is unavailable [42,44,46].

(2) Transverse processectomy

Another reported method for BS resection surgery is transverse processectomy. This method differs from the previously described technique as it only resects the TP without directly removing the pseudoarticulation. The therapeutic principle

is explained as blocking the path through which mechanical stress from the spine is transferred to the pseudoarticulation [47]. After making a skin incision approximately 2 to 4 cm from the midline, 3.5 to 4 cm laterally, access is gained between the multifidus and longissimus muscles to expose the base of the L5 TP and the upper part of the sacral ala. To avoid damaging the iliolumbar ligament and pseudoarticulation, the lateral end of the L5 TP is not exposed, and space is created by accessing only its base. The upper and lower edges of the L5 TP are palpated, and a high-speed drill is used to cut the base of the L5 TP, maintaining at least a 0.5 cm cutting gap to prevent rejoining. A tubular retractor may be used based on the surgeon's preference. The resected L5 TP can be removed en bloc or in pieces using a pituitary rongeur. Bone wax can be applied to the cut surface of the sacrum to prevent excessive bleeding. Compared to pseudoarthrectomy, transverse processectomy is less invasive and has a shorter operation time, but it is less effective at relieving pain from the pseudoarticulation [47]. The therapeutic principle of transverse processectomy is not fully understood, and it is assumed to reduce the mechanical load on the pseudoarticulation by blocking the path of stress transmission from the spine. However, there is a risk of rejoining or nonunion of the TP, leading to the recurrence of symptoms. Therefore, careful patient selection is essential, and this technique is recommended for patients with mild symptoms or those who are not suitable candidates for more invasive procedures.

(3) Anterior approach technique

The anterior approach technique involves accessing the pseudoarticulation through an anterior incision, allowing for direct visualization and resection of the pseudoarticulation without disturbing the posterior structures of the spine. This technique is less commonly reported in the literature. It is typically reserved for cases where the pseudoarticulation is anteriorly positioned or when there is a need to address other anterior spinal pathologies simultaneously. The approach requires careful planning and understanding of the vascular and visceral anatomy to avoid complications. The anterior approach may offer advantages in reduced muscle dissection and potentially quicker recovery times, but it also carries risks associated with abdominal surgery, such as injury to the great vessels, ureter, or intestines. This technique is considered for patients with specific anatomical considerations or when a combined anterior-posterior approach is necessary to address complex spinal pathologies in addition to BS. Due to the complexity and potential risks, it is typically performed by surgeons with expertise in anterior spinal surgery and collaboration with vascular or general surgeons as needed.

2) Nerve root decompression

There are cases where L5 radiculopathy accompanies far-out syndrome. The L5 nerve root is lateral to the L5–S1 disc, lateral to the L5 TP, and medial to the pseudoarticulation. The L5 root is compressed between the impingement of the L5 TP and the sacral ala, causing symptoms [48]. Therefore, the main surgical process to decompress the L5 nerve root involves expanding the pathway of the L5 root by partially resecting the bony structure surrounding it, namely the L5 TP, sacral ala, and pseudoarticulation, which can mostly be achieved through a posterior approach [23,49,50]. Abe et al. [51] have reported a case where neural decompression was performed using an anterior approach for a patient complaining of radiating pain due to far-out syndrome caused by LSTV. This patient underwent neural decompression through an extraperitoneal approach due to prominent bony spur formation in the anterior exit zone of the lateral wall of the L5 root foramen, reporting good clinical outcomes. However, this case has limitations in that symptoms took extended period to improve after surgery, and the possibility of improvement due to natural progression rather than surgical intervention cannot be entirely ruled out. They also advised that reducing the tightness of the root due to the surgical position could decrease the damage to the root during surgery.

3) Fusion

The fusion technique has traditionally been adopted in most of the literature reported so far, utilizing pedicle screwing and intersegmental posterolateral fusion, and in some cases, introduced for symptomatic BS using a tubular retractor system [52]. However, it seems no additional techniques are needed because it is BS. Fusion is more invasive compared to resection, with concerns of higher surgical complications and, in the long term, known to induce adjacent segment degeneration, potentially causing other problems. Nonetheless, there are reasons why fusion can sometimes be a more viable option in the surgical treatment of BS.

Firstly, in cases where discogenic pain exists simultaneously at the LSTV level. In such cases, resection alone may not satisfactorily improve symptoms, and discogenic pain might worsen due to increased intersegmental movement after resection. Dhanjani et al. [53] reported long-term good outcomes from classical fusion surgery on a 13-year-old female patient with symptomatic Castellvi type IIa BS, who showed extensive TP bridging, considering the disc of that segment as a potential source of pain.

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Another crucial point not to be overlooked in deciding on fusion is confirming the existence of pain generators at the adjacent segment above LSTV, L4–5, and the SI joint. If symptomatic disc degeneration, facet arthritis, spondylolysis, or SI arthritis were not identified before surgery and existed in adjacent segments, physical stress due to weight-bearing after fusion surgery for some types of BS could exacerbate persistent pain in these areas. It is worth noting that compared to the non-LSTV population, LSTV can have reduced intersegmental mobility, potentially leading to compensatory hypermobility in adjacent segments [4], which has been reported as a primary cause of disc degeneration [36]. Jenikar et al. [54], in their cohort observational study comparing patients with and without LSTV, reported that LSTV results in more degenerative changes in the adjacent upper segment and additionally. Therefore, if pain generators are diagnosed in the upper segment or SIJ while planning fusion for the LSTV segment, it may be necessary to plan for multilevel fusion, including those segments, with surgical decisions considering the risk-benefit.

Mikula et al. [55] reported that comparing the clinical efficacy of a group that underwent resection of pseudoarticulation with a group that underwent fusion for symptomatic BS, fusion showed superior pain improvement in both short-term outcomes within 6 months and long-term outcomes beyond 12 months. Notably, the rate of maintained pain improvement until the long-term outcome was statistically significantly different, with 28% in the resection group compared to 78% in the fusion group, which is worth considering.

2. Endoscopic Surgery

1) Full endoscopy

With the advancement of endoscopic spinal surgery techniques, various attempts at surgical interventions for BS have been reported. Replacing traditional surgical methods with endoscopic procedures, such as pseudoarticulation or transverse processectomy and root decompression, allows for less invasive operations that perform most of the surgical process similarly, with clinical effects comparable to conventional methods. The endoscopy techniques reported for BS to date are summarized in Table 1.

(1) Nerve root decompression for treating far-out syndrome

Paudel et al. [56] reported the results of performing a full endoscopy on 3 patients diagnosed with far-out syndrome caused by LSTV, who did not respond to conservative treatment. This report is the first of its kind regarding full endoscopy for BS. The patients were diagnosed preoperatively with compression of

Table 1. Summary of the current literature on endoscopic spine surgery for Bertolotti syndrome

Study	Year	Study design	No. of cases	Symptoms	Type of LSTV*	Mean age (yr)	Anesthesia	Procedure	Follow-up period (mo)	Outcome†
Full endoscopy										
Paudel et al. [56]	2017	Cases report with technical note	3	Case 1 LBP, leg pain	IIa	56.7	Not reported	Nerve root decompression	Case 1 13	Case 1 LBP: 5 → 2/ Leg pain: 8 → 2
				Case 2 LBP, leg pain, motor weakness					Case 2 14	Case 2 LBP: 5 → 1/ Leg pain: 8 → 3
				Case 3 LBP, leg pain					Case 3 12	Case 3 LBP: 7 → 3/ Leg pain 4 → 2
Yoo et al. [58]	2019	Case report	1	LBP, leg pain	IIb	64	Local	Transverse processectomy	Not reported	Symptoms got relieved immediately
Wu et al. [45]	2021	Technical note	N/A	N/A	N/A	N/A	General	Resection of pseudoarticulation	N/A	N/A
Stein et al. [57]	2023	Case report	1	Low back pain. referred leg pain	IIb	57	General	Resection of pseudoarticulation	Not reported	7 → 4
Unilateral biportal endoscopy										
Heo et al. [59]	2019	Case series with technical note	14	Unilateral radiating leg pain	Not reported	59.5	General or epidural	Nerve root decompression	11.0 ± 5.0[3]	Leg pain: 8.4 ± 1.1 → 2.8 ± 1.4‡

LSTV, lumbosacral transitional vertebra; LBP, low back pain; N/A, not applicable.
*Classified by Castellvi's classification. †The numeric value represents a pain score out of a maximum of 10 points. ‡Mean±standard deviation.

the L5 root between the pseudoarticulation at the TP and the sacral alar, causing sciatica. The authors introduced methods of achieving L5 root decompression by removing the distal part of the TP with high-speed burr drilling through a direct dorsal approach to the endoscope's working area and by resecting parts of the TP or pseudoarticulation similar to percutaneous endoscopic transforaminal lumbar discectomy. They noted that patients showed good clinical outcomes after more than a year postsurgery, suggesting that this direct target-oriented surgery, which minimizes soft tissue injury compared to classical methods using microscopes or tubular retractors, is advantageous for postoperative recovery. Specifically, preserving the iliolumbar ligament, crucial for the stability of the lumbosacral junction, was highlighted as a benefit.

(2) Pseudoarticulation resection

The first report of performing resection of pseudoarticulation using full endoscopy for symptomatic BS was in 2021, with Stein et al. [57] reporting a similar surgical method 2 years later. Wu et al. [45] provided a detailed description of the surgical technique in a technical note. They described entering the endoscopy to the target area through a 1-cm skin and fascia incision at the midpoint of the pseudoarticulation under fluoroscopic guidance. They proceeded with drilling from the ventrolateral margin of the pseudoarticulation articulating with the highest part of the sacral ala (PH point) in a superficial to deep fashion towards the dorsal medioinferior margin adjacent to the superior articular process (MS point), followed by L5 root decompression. Wu emphasized the importance of preoperative MRI to check the course of the L5 nerve root, secure identification of the PH point to prevent drilling-induced nerve injury and retroperitoneal space penetration and maintain a 9-mm gap between the dysplastic TP and sacral alar to prevent recurrence of fusion. Stein et al. [57] mentioned that extensive resection provides superior pain relief.

(3) Transverse processectomy

In 2019, a report was published on performing transverse processectomy using full endoscopy for symptomatic BS. Yoo et al. [58] reported on a 64-year-old female patient with left leg pain, initially diagnosed with foraminal stenosis at L5–S1 and treated with foraminotomy using full endoscopy without symptom improvement. Subsequent identification of pseudoarticulation as the pain generator through a pseudoarticulation block led to symptom improvement through a second surgery. The authors noted that this method, which involved drilling the base of L5's TP with a high-speed burr, replicated a technique reported by Ju et al. [47] in 2017 using microscopic surgery. This surgical approach can block the pathway of mechanical stress from body weight on the pseudoarticulation and simultaneously perform L5 root decompression in cases of far-out syndrome. The anatomical recognition of the TP being relatively straightforward in the operative field facilitates the surgery and identification of the L5 root, thus combining the advantages of the reported transverse processectomy method with those of full endoscopy.

2) Unilateral biportal endoscopy

In 2019, Heo et al. [59] were the first to report on unilateral biportal endoscopy (UBE) conducted for radiculopathy caused by far-out syndrome. This is the only report using UBE for symptomatic BS, including clinical outcomes for 14 cases and a technical note. According to the surgical procedures of authors, the surgery was performed under general or epidural anesthesia. Two skin incisions were made 1 cm lateral to the lateral border of the L5–S1 pedicle and 1 cm above and below the midpoint of the foramen, after which an endoscopic channel and a working channel were formed at each incision. The decompressive procedure began with the partial drilling of the lower portion of the TP and the lateral portion of the isthmus and the facet wall, exposing the foraminal part of the L5 root and continued by following the course of the nerve root. Decompression was performed from the superior portion of the ala medially to laterally, drilling out the pseudoarticulation while simultaneously decompressing the root.

The authors presented clinical outcomes after an average follow-up of 11 months, stating that UBE approaches demonstrated shorter operation times and less blood loss while minimizing damage to posterior muscle and ligamentous structures. They also highlighted the advantages of reduced postoperative pain and easier recovery. However, they noted disadvantages, including retroperitoneal fluid collection due to irrigation fluid, the possibility of incomplete decompression, and the steep learning curve of endoscopy. Specifically, they emphasized the need to explore and remove any concomitant extraforaminal disc herniation after decompression around the pseudoarticulation, as it may be associated with a sudden aggravation of pain. The surgical process introduced by Heo et al. [59], which allows for L5 root decompression from the foraminal to the extraforaminal area and involves verifying the L5 root from proximal to direct vision sequentially to lateral decompression, is considered relatively safer compared to methods introduced by other authors.

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CONCLUSION

Surgical intervention should only be considered for symptomatic BS when conservative treatments fail. LSTV can cause symptoms in various forms, including pseudoarticulation, facet arthritis, disc degeneration, adjacent segment degeneration, and far-out syndrome. A precise presurgical investigation of the distribution of pain generators is necessary, and the appropriate surgical treatment should be chosen based on the type of pseudoarticulation. Before proceeding with surgery, careful consideration of the expected benefits of pain relief from surgical intervention is required. While endoscopic surgery for BS has been attempted numerous times and demonstrated successful outcomes, additional research and evidence are needed.

NOTES

Conflict of Interest

CIJ and PK, are member of the Editorial Board of Journal of Minimally Invasive Spine Surgery & Technique, are the author of this article. However, they played no role whatsoever in the editorial evaluation of this article or the decision to publish it. The other authors have no conflict of interest to declare.

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Uniportal Dual Mode Dry-Saline Endoscopy for Lumbar Disc Herniation

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Objective: Posterior dry medium endoscopic lumbar discectomy techniques have been successfully used to treat lumbar disc prolapse. A drawback of these techniques is repeated blood staining of the scope tip while working close to the surgical target. To address this drawback, we modified the design of the previous Arthrospine system and made it compatible for use in air and saline medium to treat lumbar, cervical, and thoracic disc prolapse. Herein, we describe the operative technique and results of lumbar discectomy in a dual (air/saline) medium using this system.

Methods: Eighty patients underwent endoscopic discectomy using the Arthrospine Duo system for lumbar disc prolapse. The procedure was conducted through a muscle dilatation approach using 5-mm and 10-mm dilators. The Arthrospine Duo tube was passed over a 10-mm dilator, the working insert was adjusted over the tube in a press-fit manner, and endoscopic discectomy was performed using a 30° arthroscope and conventional microdiscectomy instruments in an air or saline medium.

Results: As per the modified MacNab criteria, 80% (n=64) of patients had excellent, 12.5% (n=10) good, 6.25% (n=5) fair, and 1.25 patients (n=1) had poor results. The leg pain visual analogue scale improved from 7.87±0.68 to 1.3±0.67 at 2 years of follow-up. As complications, dural tears and transient paraesthesia occurred in 4 patients (5%) each, nerve root injury in 1 patient (1.25%), and superficial wound infection in 5 patients (6.25%).

Conclusion: The uniportal Arthrospine Duo system can be used in air/saline medium and is an excellent minimally invasive option for lumbar discectomy.

Key Words: Lumbar disc herniation, Spine endoscopy, Disc prolapse, Discectomy

INTRODUCTION

Endoscopic-based techniques in dry (Destandau, Arthrospine) and saline medium (percutaneous endoscopic lumbar discectomy [PELD], unilateral biportal endoscopy) are excellent methods for minimally invasive surgical treatment for symptomatic lumbar disc prolapse. One of the drawbacks observed with dry techniques is frequent blood staining of the scope lens tip when working close to the surgical target. This frustrates the surgeon and also adds to increased operative time. Excessive bleeding or accidental dural injury while working in saline endoscopy may necessitate conversion to an open/microscopic technique. To address this problem, we modified and designed the second-generation Arthrospine Duo system which can be used in both air and/or saline medium. There is no such study about a single portal dual mode dry-saline endoscopic spine

system utilizing both dry and saline medium for the lumbar discectomy technique reported in the literature. The objective of the current study is to describe innovative instrumentation, operative technique, and results in patients who underwent discectomy by Arthrospine Duo system for lumbar disc prolapse.

MATERIALS AND METHODS

From January 2016 to December 2016, 80 patients suffering from prolapse lumbar intervertebral disc were operated on by the Arthrospine Duo system. Prior ethical approval was obtained from ethical committee of the Trinity Hospital and Medical Research Institute, Zirakpur (Ref Number 1/2015).

1. Inclusion Criteria

Patients with single-level lumbar disc prolapse with unilateral radiculopathy with good clinical and radiological correlation.

2. Exclusion Criteria

Patients with bilateral symptoms, more than 1 level, double root involvement, cauda equina syndrome, and complete or partial foot drop and whose clinical symptoms did not match the magnetic resonance imaging (MRI) picture. Interlaminar approach for endoscopic discectomy by Arthrospine Duo system (GESCO Healthcare, Chennai, India) was performed in patients who did not respond to medicines and physiotherapy for duration of 3 months. There were 45 males and 35 females aged between 18 and 60 years (mean, 38.4 years). The body mass index ranged from 26.1 to 33.0 kg/m^2 (mean, 29.49 kg/m^2) (Figure 1). The delay between the onset of symptoms to surgery was between 3 months to 1 year.

Levels operated upon included L1–2 (n=1), L2–3 (n=1), L3–4 (n=4), L4–5 (n=69), and L5–S1 (n=25). Forty-five patients had radiculopathy on the right side and 35 on the left side. There were 58 paracentral, 10 central, 10 sequestrated, and 2 extraforaminal herniations. Average blood loss was 30 mL (range, 20-50 mL). There was no loss to follow up.

Written consent for lumbar endoscopic discectomy, anesthesia, pre-, intra-, and postoperative photography, and video documentation were taken for all patients. Clinical outcomes were analyzed using the modified MacNab criteria [1] and visual analogue scale (VAS) on postoperative day 2 and at the final follow at 2 years [2]. Patients were followed up maximum of up to 2 years duration. Out of 80 patients, 70 patients were given spinal anesthesia and 10 patients opted for general anesthesia. The postoperative protocol involved the mobilization of patients once the effect of anesthesia was over. Back exercise program and posture care were also taught at the same time. The rehabilitation program was altered in patients with unusual pain responses and dural tears. The patients were discharged on 2nd postoperative day. Postoperative follow-up was carried out on the 2nd, 6th, 12th, and 24 months. Patients were advised to remove water impermeable dressing on 3rd day and to keep the wound open thereafter since there were no sutures outside so these patients were not called for suture removal. They were only advised to report back in case there was any kind of drainage from the wound, fever, backache, or recurrence of sciatica. Back movements, neurology and straight leg raise were tested on every visit. During every follow-up visit, subjective perception of back and leg pain, work ability, neurological deficits, the need for analgesics, and the ability to return to work were

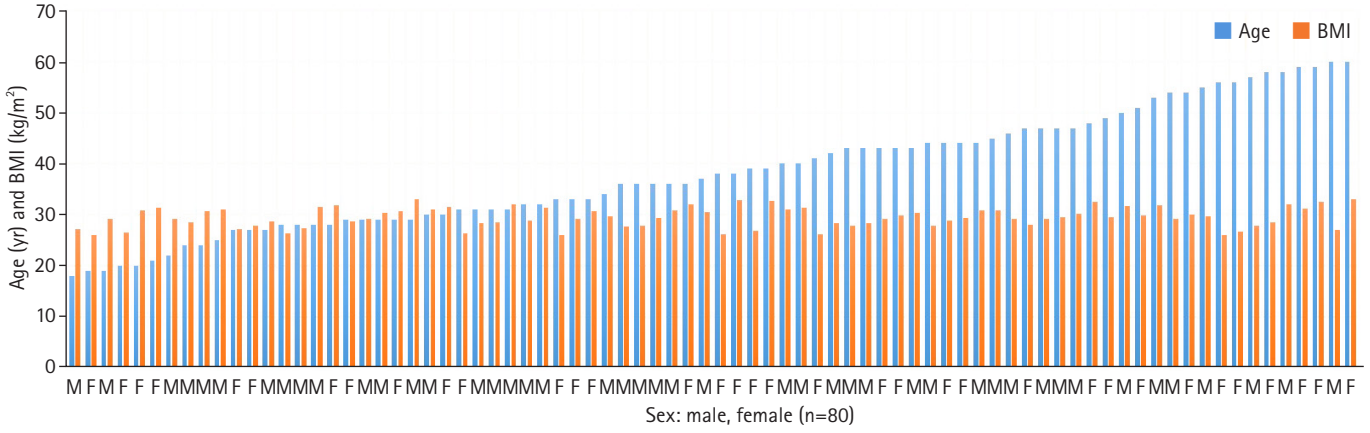

Figure 1. Age and body mass index (BMI) of patients (n=80).

analyzed. Postoperative MRI was only ordered in patients who had not shown satisfactory response to surgery or we suspected recurrence (Figures 2 and 3). Patients were followed up for a maximum of up to 2 years duration.

3. Arthrospine Duo System Assembly

Arthrospine Duo (GESCO Healthcare, Chennai, India) system assembly comprises of single inflow cannula sheath which is compatible with 0° or 30° 4-mm arthroscope, set of 5-mm and 10-mm 2 cannulated dilators, 10-mm dilator has specially designed cobbs type tip to aid in soft tissue retraction from interlaminar window, Arthrospine conical oval tube 7 cm in length with lower channel of 12 mm^2×8 mm^2 and upper channel of 20 mm^2×8 mm^2, 2 Arthrospine working inserts air (A-1), saline (S-2) with a provision of tightening screw, working insert air (A-1), has 3 ports—first 6-mm port for scope sheath, second 4-mm port for suction cannula, and third 7.5-mm port for working instruments. Working insert saline (S-2), is covered with a silicone rubber cap and comprises two 5-mm ports, one port for passage of scope with sheath and another for passage of surgical instruments (Figure 4A–F). The saline enters through the single inflow sheath which is connected to the saline insert (S-2) which sits over the Arthrospine tube. The fluid

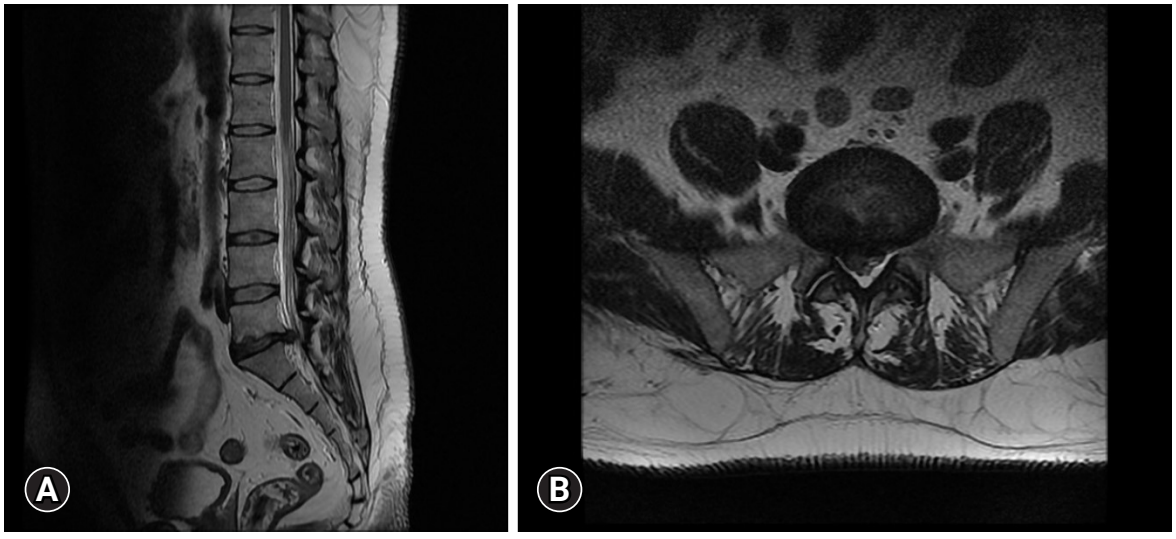

Figure 2. Preoperative magnetic resonance imaging: sagittal (A) and axial (B).

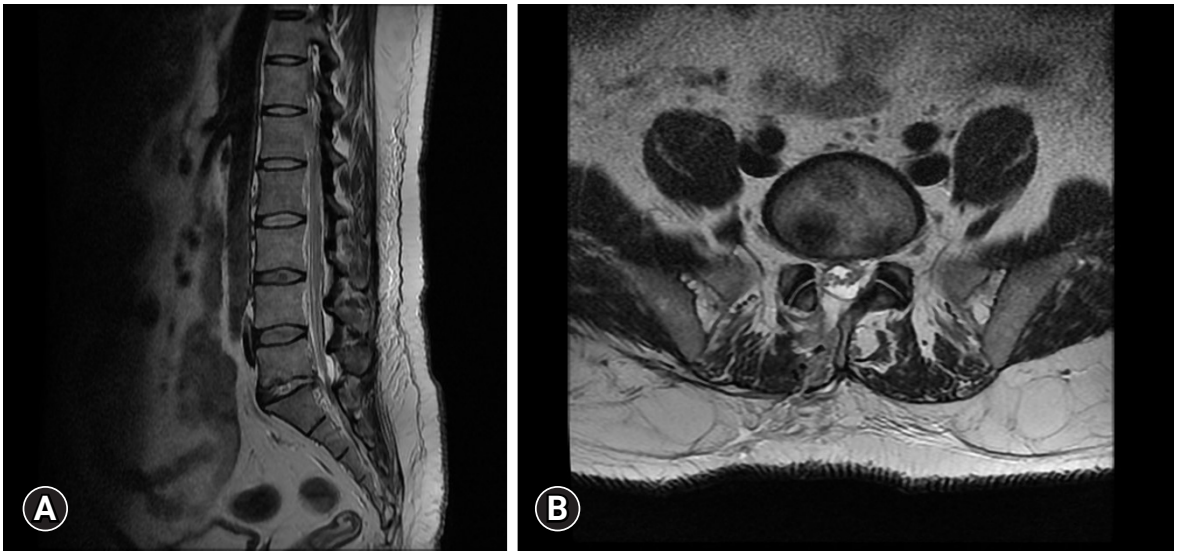

Figure 3. Postoperative magnetic resonance imaging (3 days): sagittal (A) and axial (B).

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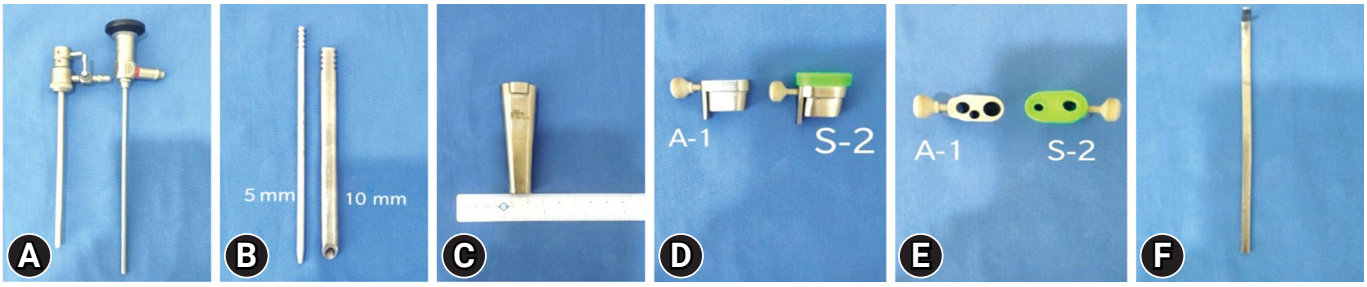

Figure 4. Arthrospine Duo system assembly. (A) Single cannula high flow arthroscopic sheath and 4 mm, 30° scope. (B) Dilators 5 mm and 10 mm (with special pointed tip). (C) Arthrospine duo tube. (D) Arthrospine duo working insert side view air (A-1) and saline (S-2). (e) Arthrospine duo working insert top view air (A-1) and saline (S-2). (F) Integrated dural and nerve root retractor.

enters into the operative field to create a hydrostatic pressure at the working area and continuously exits out of the second port of (S-2) insert which acts as a working port for inserting instruments (Figure 5). Radiofrequency equipment is an additional requirement for saline endoscopy for ablation and coagulation of tissues. We used the VAPR VUE (DePuy Mitek Inc., subsidary of Johnson & Johnson, Raynham. MA, USA) radiofrequency device, which can also be used in biportal and uniportal endoscopic surgery. Integrated nerve root and dural retractor are used for dural and nerve root retraction. The system is compatible with 0° and 30° 4-mm arthroscopes. However, we recommend a 30° arthroscope as it has a wide-angle view and enables better recess visualization. The tightening screw on the left side of the working insert allows the sheath and scope to be moved up and down, scope rotation clock or anticlockwise, and locked at the desired position. A discoscopic view is possible by negotiating the scope into intervertebral disc space in the saline medium. The system is handheld and mobile. The surgeon's left-hand controls the device and can tilt the system cephalad, caudal, medial, and lateral and can rotate clock and anticlockwise which enables the surgeon to navigate in the spinal canal including recess all around the dura and nerve roots (Figure 6A–C).

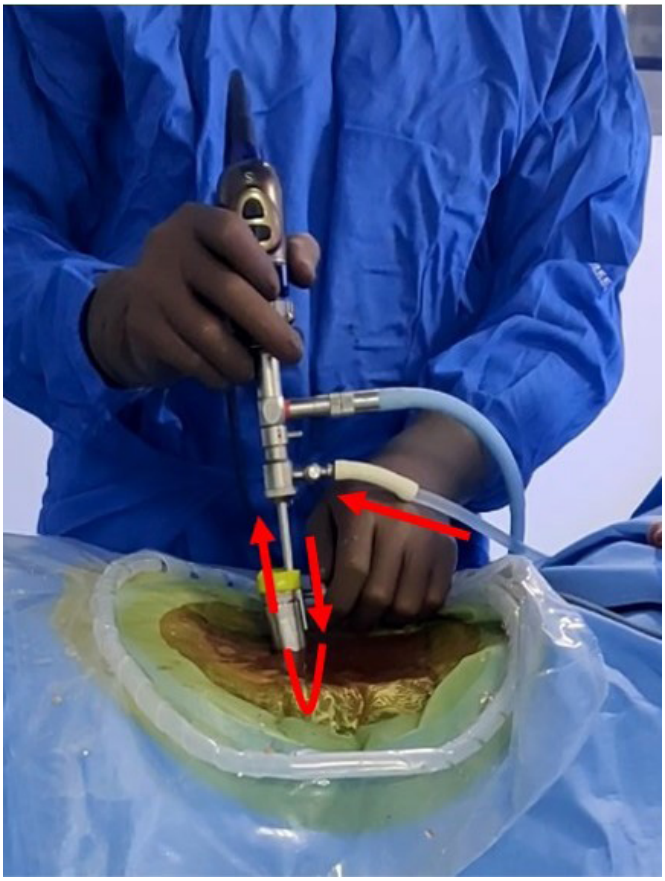

Figure 5. Arthrospine Duo saline technique: The saline enters through the single inflow sheath which is connected to the saline insert (S-2) which sits over the Arthrospine tube. The fluid enters into the operative field to create a hydrostatic pressure at the working area and continuously exits out of second port of (S-2) insert which acts as a working port for inserting instruments.

4. Operative Technique

With the patient in a prone position over bolsters, the back of the patient is cleaned and draped. After administration of spinal or general anesthesia symptomatic lumbar level to be approached is confirmed using lateral fluoroscopy by inserting an 18-gauge spinal needle into the paraspinal musculature approximately one finger-breadth (1.5 cm) lateral to the midline. The needle is directed laterally towards the facet (to avoid inadvertent dural puncture) and repositioned until it is directly in line with the disc space. The spinal needle is then withdrawn and a 10- to 15-mm-long skin and fascial incision is made at the puncture site. Through this incision, a 5-mm dilator is inserted transmuscular towards the spinolaminar junction under tactile and fluoroscopic control (Figure 7A), followed by pas-

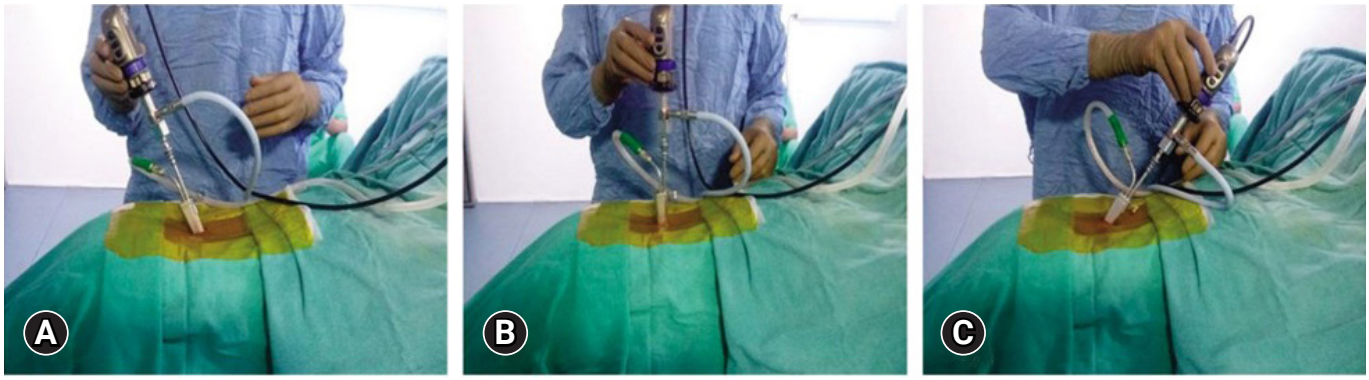

Figure 6. Mobility of tube: cephalad (A), centre (B), and caudal (C).

sage of a second 10-mm cannulated dilator with special cobs type tip over first dilator (Figure 7B), retraction of muscles and fibromuscular tissue from spinolamina junction, interlaminar window up to facet is achieved by 10-mm dilator. However, care must be exercised to prevent advancing the initial dilator into the spinal canal. The Arthrospine tube is introduced over the dilator over the symptomatic level then both dilators are withdrawn (Figure 7C). Arthrospine working channel air (A-1) is then snugly fit over the Arthrospine tube by simple press-fit way. The arthroscope is locked in the sheath and is connected to the endoscopic camera under sterile conditions. Scope with sheath and suction tube are introduced into their respective ports (Figure 7D). At this stage, the correct placement of the Arthrospine tube is checked under image intensifier guidance, to prevent wrong level entry in both anteroposterior (AP) and lateral views. For saline endoscopy, fluid comes out through a specially designed forward flow single portal endoscopic sheath. This fluid enters through one port and creates hydrostatic pressure at the surgical field which helps in tissue retraction and controls hemostasis and comes out through another working port. This is gravity gravity-aided open fluid flow system and no pressure pump is used here (Figure 7E). A radiofrequency probe is used to control hemostasis and to ablate tissues in saline, where ever needed. Arthroscopic 4-mm burr can be used to burr lamina to aid flavum detachment. For central and paracentral disc herniations, an interlaminar approach was utilized. For extraforaminal or far lateral disc prolapse, tube docking is done lateral to isthmus/ pars and after removing the foraminal ligament and part of the superior articular process tip, discectomy can be carried out. Under endoscopic visualization, fibromuscular tissue bulging in the mouth of the tube is shrunk with microbipolar coagulation (dry mode) or radiofrequency probe (saline view), this is further aided by the removal of soft tissue by pituitary rongeur. Cottonoids can also be used over the lamina to push away the fibro-muscular tissue and clear the lamina. Once boundaries of the interlaminar window such as superior and inferior lamina, facet joint, and spinolaminar junction are clearly visualized then initial bone work is started with a 2- or 3-mm kerrison punch or arthroscopic 4-mm burr at spinolamina junction thus detaching flavum from under surface of upper lamina. This is followed by partial or complete excision of ligamentum flavum leading to exposure of the dural sac and nerve root. Once neural structures are adequately exposed, the endoscope is advanced further to magnify and enhance the distinction between dura, root, and extruded disc. As the scope tip goes closer, it is prone to repeated staining by blood in dry mode at this stage surgeon can switch over to saline mode which mitigates staining of the scope tip and ensures excellent visualization (Figure 7F). Once the nerve root has been identified, it is retracted using a nerve root retractor or putting a cottonoid lateral to the shoulder of the root. The epidural veins are coagulated by microbipolar in dry endoscopy or radiofrequency probe in saline endoscopy. Depending on the pathology - annulotomy, discectomy of free loose fragments can be carried out (Figure 7G). An angled probe can be used to retrieve up/ down migrated or medial fragments while minimizing neural retraction. The scope can be further advanced into the disc space, in saline medium, to better appreciate the intradiscal pathology. At the end of the procedure, hemostasis of the muscle layers is achieved by microbipolar or radiofrequency coagulation. The tube is withdrawn and the lumbar fascia is sutured using vicryl 2-0 suture followed by the closure of the skin in a subcuticular fashion (Figure 7H) followed by water impermeable dressing. No drain is used.

5. Statistical Analyses

Statistical analyses were performed with GraphPad Prism

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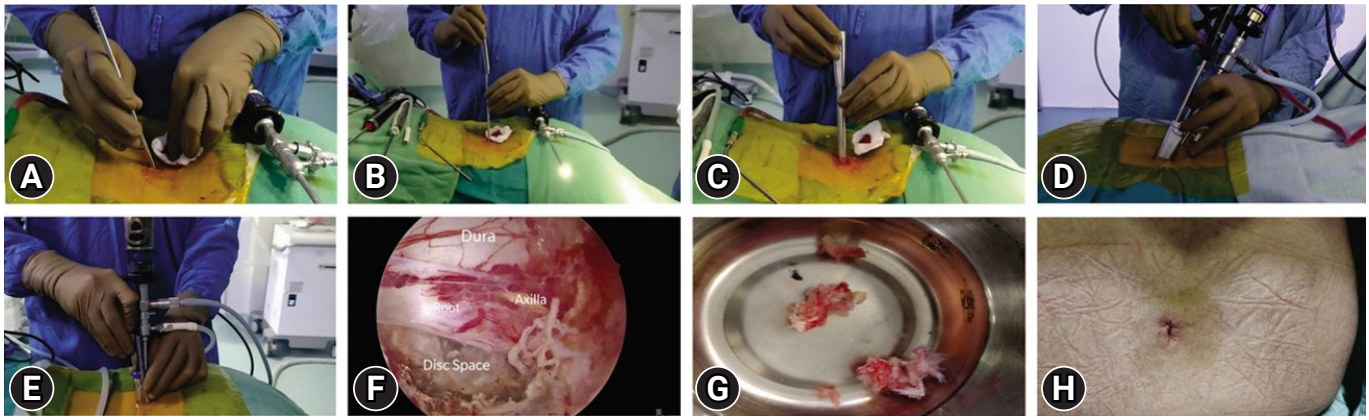

Figure 7. Operative technique. (A) 5-mm dilator insertion through 8- to 10-mm skin and facial incision. (B) Passage of 10-mm dilator over first one. (C) Sliding of Arthrospine tube. (D) View of Arthrospine Duo working insert air (A-1) with ease of angulation. (E) View of Arthrospine Duo working insert saline (S-2). (F) Endoscopic saline view of decompressed nerve root. (G) Removed disc fragments. (H) Cosmetic skin incision.

8.0 (GraphPad Software, Inc., San Diego, CA, USA). Continuous variables were presented as means±standard deviations. Repeated analysis of variance and Tukey multiple-comparison posttest were performed to compare the differences at 3-time points of VAS pain score. Differences among the 3 groups were found highly significant at a p-value of <0.05.

RESULTS

Clinical outcomes were assessed using modified MacNab criteria [3] and a numeric rating scale for back and radiating leg pain [4]. As per modified MacNab criteria, 64 patients (80%) had excellent, 10 (12.5%) good, 5 (6.25) fair, and 1 patient (1.25%) had poor results (Table 1). VAS numerical scale for leg pain improved from 7.87±0.68 to 1.3±0.67 at 2-year follow-up (Tables 2–4; Figure 8]. Average operative time was 45 minutes (range, 30–80 minutes). Intraoperative minor dural tears were observed in 3 patients (3.75%) which we managed by placing a gel foam over the defect followed by secure layered closure. They remained asymptomatic in the postoperative period hence rehabilitation protocol was not altered in these patients. They were told to report to the hospital if symptoms of giddiness, nausea, headache, fever, and cerebrospinal fluid leakage were observed from the wound site. Recurrent disc herniations occurred in 4 patients (5%) and underwent revision discectomy by Arthrospine Duo system. Nerve root injury occurred in 1 patient (1.25%) during dry medium endoscopy which contributed to poor results. Superficial delayed wound healing was observed in 5 patients (6.25%) which healed in 12-day time. These were managed and improved by regular wound dressings. All the patients were able to resume sedentary work in a week and routine activities 45 days after the procedure.

Table 1. Distribution of outcomes according to MacNab criteria (n=80)

MacNab criteria	No. (%)
Excellent	64 (80.0)
Good	10 (12.5)
Fair	5 (6.25)
Poor	1 (1.25)

Table 2. Visual analogue scale (VAS) pain scores preoperatively, at day 2 postoperatively, and at 2 years postoperatively

	Preoperative	Postoperative day 2	Postoperative 2 years
VAS back pain	4.15 ± 1.55	3.06 ± 1.25	2.2 ± 1.09
VAS leg pain	7.87 ± 0.68	2.2 ± 1.09	1.3 ± 0.67

Values are presented as mean±standard deviation.

DISCUSSION

Laminectomy and discectomy advocated by Mixter and Barr [1] in the surgical treatment of prolapsed lumbar disc were associated with high morbidity hence many minimally invasive techniques were devised to reduce approach-related morbidity. Techniques such as chymopapain, percutaneous lumbar nucleotomy, transforaminal and automated disc removal devices [2,5–8], were minimally invasive but have not proven as effective as open lumbar disc surgery. The indications for these procedures have generally been limited to contained lumbar disc herniations. Bony or ligamentous pathology associated with disc herniation was a contraindication to these techniques. Microdiscectomy was introduced by Caspar [9] and Williams [10] and has been a gold standard. The disadvantage

Table 3. Repeated-measures 1-way analysis of variance multiple comparisons for back visual analogue scale pain scores

Tukey multiple comparisons test	Mean difference	95% CI of difference	Significant	Adjusted p-value
Preoperative vs. postoperative day 2	1.088	0.727 to 1.449	Yes	< 0.001
Preoperative vs. postoperative year 2	1.763	1.354 to 2.171	Yes	< 0.001
Postoperative day 2 vs. postoperative 2 years	0.675	0.391 to 0.959	Yes	< 0.001

CI, confidence interval.

Table 4. Repeated-measures 1-way analysis of variance multiple comparisons for leg visual analogue scale pain scores

Tukey multiple comparisons test	Mean difference	95% CI of difference	Significant	Adjusted p-value
Preoperative vs. postoperative day 2	5.675	5.400 to 5.950	Yes	< 0.001
Preoperative vs. postoperative year 2	6.550	6.299 to 6.801	Yes	< 0.001
Postoperative day 2 vs. postoperative 2 years	0.875	0.645 to 1.105	Yes	< 0.001

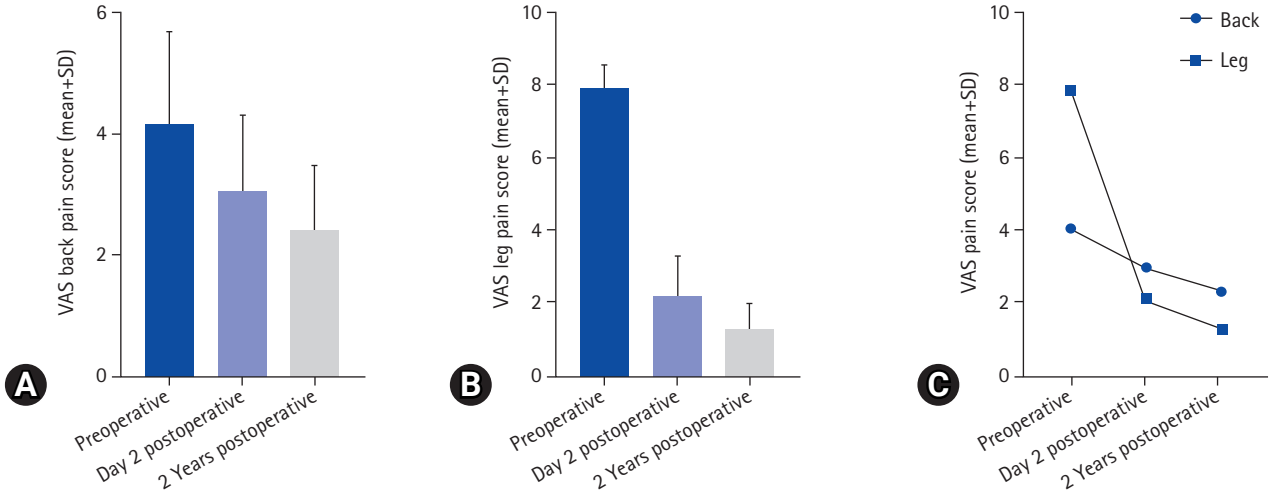

Figure 8. Visual analogue numerical scale visual analogue scale (VAS) pain score preoperatively, at day 2 and 2 years after surgery back (A), leg (B), scatter (x, y) plot (C) for back and leg VAS pain score.

of these techniques, however, is, that the eye (lens of the microscope) is away from the surgical target, and the dissection of the short segmental paraspinal muscles (multifidi) from their bony attachments, can result in scarring as well as segmental denervation [11–14]. To further minimize approach-related morbidity to the spine, techniques by Destandau [15], Arthrospine [16], METRx [17–19], Full endoscopic [20], unilateral biportal endoscopy [21] have been successfully used through traditional posterior approach to treat all type of disc herniations. These authors have reported a success rate between 73% and 94%. Ruetten et al. [22] in 331 patients with lumbar disc herniation and minimum follow-up at 2 years found complete relief in 82% of patients. Only 13% had only occasional pain at the final follow-up. The recurrence rate was 2.4%. In another retrospective study by Choi et al. [23] in 67 patients with L5–S1 soft disc herniation treated with interlaminar PELD with more than 1.6 years of follow-up. Ninety point eight percent of patients showed favorable results. The mean hospital stay was 12 hours. The average time to return to work was 6.79 weeks. Complications included 2 cases of dural injury with cerebrospinal fluid leakage, 9 cases of transient dysesthesia, and 1 case of recurrence. Two patients required conversion to open procedure at the initial operation. Chumnanvej et al. [24] reported 91.6% excellent outcomes in their prospective analysis of 60 patients with 26 months of follow-up. Our results of the present study correlate well with the aforementioned studies. 80% excellent results in our study are comparable with those of Lyson et al. [25], Ranjan and Lath [26], Jhala and Mistry [27], Kaushal and Sen [28], and Oertel et al. [29], and other authors [30,31]. Notably, the complication rate associated with the present technique for lumbar discectomy is comparable with that of standard existing techniques. In the present study, dural injury and recurrent disc herniations were observed in 4 patients (5%), nerve root injury occurred in 1 patient (1.25%), superficial de-

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layed wound healing in 5 (6.25%), and transient paraesthesias in 4 patients (5%). Recurrence rates of 5%, in our study, are comparable with Caspar [9], Williams [10], and Ebeling et al. [31]. These authors have reported reoperation rates of 5.5%, 5.7%, and 3%, respectively. The Arthrospine duo is a uniportal system that is used like a Destandau system in a dry medium and can be converted into a saline endoscopy medium by changing the top working insert. It is different from biportal surgery, which requires free hand control of both camera and instruments in each hand that requires a certain level of triangulation skill of the surgeon whereas the duo system utilizes a mobile conical tube which is controlled by one hand of the surgeon, inside which the triangulation is not needed as instruments and camera are coming in through the same tube. The system can be used in the anterior cervical approach in dry medium which is not possible with biportal surgery. Microendoscopic discectomy (MED) usually requires different sets of tubes that get fixed to the table henceforth lack of mobility in MED is a disadvantage. MED is done in a dry medium; biportal surgery is a fluid medium surgery. Compared to uniportal full endoscopy, the duo system does not require long, fine instruments which are prone to breakage and entail a recurring cost. A conventional bayonet Kerrison punch and standard arthroscopy burr can be used which is very economical in the duo system. The full endoscopic system requires different sets in cervical, lumbar, and dorsal levels whereas a single tube can be used in all levels in the duo system. The duo system can be used for multilevel degenerative spinal diseases for discectomy, and stenosis decompression where a single incision can be used to address L4–5 and L5–S1 by angulating the tube. If bleeding in saline becomes troublesome, then controlling becomes relatively easier in the dry medium where the camera lens can be taken away from the field to afford a bird's eye view, and the red-out phenomenon of saline gets changed to oozing in the dry medium which can be effectively controlled with gelfoam, hemostatic agents and/or microbipolar coagulation. A dural tear in a saline medium can be a problematic situation that needs conversion to either open or microtubular methods; but by changing to a dry medium in duo system, it can be attempted repair with small metal clips (anastoclips) or placement of autologous fat/muscle graft which can then be augmented with a fibrin glue; the latter will wash away in a saline medium surgery. Excess fluid usage complications like neck pain, headache, long segment epidural hematoma, seizures, blindness, and abdominal collection have been described in fluid medium surgery – the duo system uses a dry medium approach till the flavum in the midline is removed and then can be converted to saline medium to ensure safer lateral recess and contralateral decompression in fluid medium hence ensuring judicious fluid usage. The versatility of the present technique which none of the other techniques offer is its use in both dry and saline medium. The advantage of the duo system is that the drawbacks of repeated blood staining of the scope tip while working in depth during dry endoscopy are taken care of by switching over to a saline medium, which affords a clear distinction between neural and non-neural structures. Only the working tips of instruments are visible during this procedure, this further reduces the chances of neural injury. Unable to perform adequate interbody preparation and cage insertion through the duo system tube is a drawback that the surgeon can tackle by removing the tube and converting to biportal surgery where the initial incision can be used as a working portal and another portal can be created over the adjacent pedicle (on AP view) which will be used as viewing portal in fusion cases. We have not used the duo system in tumor surgery but few authors have used the Destandau system for extradural tumor resections [32–34]. The endoscopic anatomy and appreciation of structures usually changes in both dry and saline medium which requires orientation and getting used to in initial cases. To minimize the steep learning curve, short-term fellowships, hands-on cadavers, and training on models are strongly recommended.

CONCLUSION

Endoscopic lumbar discectomy by Arthrospine Duo system technique offers advantages of both dry and saline endoscopy options. The authors suggest this minimally invasive spine procedure as a feasible treatment option for prolapse lumbar intervertebral disc.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Preliminary Results of The Treatment for Failed Back Surgery Syndrome by Full Endoscopic Approach at Saint Paul General Hospital, in Hanoi, Vietnam

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Objective: Patients with radiculopathy after failed spine surgery due to restenosis, regenerated bony spurs, or inadequate decompression face high risks for morbidity or disability following massive revision operations. Therefore, fully endoscopic spine surgery could be less invasive, safer, and more effective because of accurate exposure, precise decompression, and avoidance of neural tissue injury. Our report aimed to describe the clinical result of selected patients with failed back surgery syndrome (FBSS) treated with fully endoscopic spine surgery at Saint Paul General Hospital in Vietnam.

Methods: We retrospectively reviewed 24 patients with FBSS who were treated with uniportal fully endoscopic surgery at Saint Paul General Hospital with an average follow-up period of 16 months.

Results: The patients' average age was 61 years (range, 24–83 years), and the difference between preoperative and postoperative leg pain at the last follow-up was statistically significant (preoperative leg pain visual analogue scale [VAS] = 7.1; last follow-up leg pain VAS = 0.8; $p < 0.01$). The difference in Oswestry Disability Index scores between the preoperative assessment and the final examination was statistically significant (preoperative, 57.8; last follow-up, 21.2; $p < 0.01$). According to improvements in the MacNab score, the percentage of patients who achieved good or excellent postoperative results was 75%.

Conclusion: Major open surgery as a revisional procedure in patients with FBSS syndrome has many potential risks during and after surgery. Fully endoscopic spine surgery can be a safe and effective option for selected cases with lower risk.

Key Words: Fail back surgery syndrome, Full endoscopy, Restenosis, Foraminoplasty, Decompression

INTRODUCTION

Failed back surgery syndrome (FBSS) is characterized by persistent or recurrent back pain and nerve root pain symptoms after one or more spine surgeries [1]. According to some reports, the incidence of FBSS ranges from 10% to 40% after decompressive laminectomy with or without lumbar spinal fusion [1,2]. The cause of FBSS originates from one or more factors: before, during, and after surgery [2]. This undetected compression from foraminal or lateral recess stenosis and fibrous

tissue forming after surgery causes more pain to the patient. If it does not respond to medical treatment, surgery is required to release the compressed nerve structure. However, operation on a patient with previous surgery carries many potential risks, such as dural tears, nerve damage, infection, and other serious events [3]. Most FBSS patients are old with many underlying diseases, so resurgery has a high risk of complications. In such a situation, there is a requirement for minimally invasive intervention; full-endoscopic spine surgery (FESS) can meet this requirement, and there are cases where it can be performed under local anesthesia [4]. Also, compared to open surgery, FESS allows precise access to the location of the nerve structure that needs to be released while being able to pass through adherent fibrous tissue easily [5,6]. For these reasons, reoperation in patients with FBSS is more feasible and less risky. The report aims to describe the treatment results of patients with FBSS at Saint Paul General Hospital.

MATERIALS AND METHODS

We retrospectively reviewed 24 patients with FBSS treated with full-endoscopic surgery at Saint Paul General Hospital from January 2020 to June 2023. Our local institutional review board approved this study. The selection criteria include: (1) Previous lumbar spine surgery; (2) Nerve root pain that may be accompanied by low back pain; (3) Treating doctors recorded signs of compression on computed tomography (CT) and magnetic resonance imaging in the area immediately above or below the intervention site; (4) Surgeon determined the pain generator by selective nerve root block injection; (5) Medical treatment fails. In addition, cases with cauda equina syndrome, unstable spondylolisthesis, infection, tumor, or systemic neurological disease should be excluded. Surgical results are monitored and interviewed according to the visual analog scale (VAS), Oswestry Disability Index (ODI), and MacNab criterion (excellent – no pain, no functional limitation; good – occasional back or leg pain, mild functional limitation; moderate – improvement in general function, but requires changes in work and daily life activities; poor – no improvement in function and pain) at six weeks, six months, one year, and two years after surgery. All patients signed an informed consent form before surgery and before being included in this study. Statistical data were processed using IBM SPSS Statistics ver. 20 (IBM Co., Armonk, NY, USA), comparing ODI and VAS scores simultaneously with the T-test (p<0,05).

RESULTS

1. Patient Population

According to the data we obtained (Table 1), among 24 patients with FBSS, 50% were male, with an average age of 61±15 years. Of these, 50% were patients who had previous bone fusion surgery, 16.7% had previous cement injections, and the remaining had endoscopic surgery, microsurgery, or simple open decompression surgery without fusion. All of these cases were reoperated using uniportal endoscopy at the neurosurgery department, Saint Paul General Hospital, and there were no cases of complications during or after surgery. After the follow-up period, one complication occurred due to nonunion fixation after the removal of the interbody cage and endoscopic fusion. Open surgery was performed for revision. The average surgery time is 94 minutes, with a small amount of blood loss during surgery—impossible to quantify; 58.3% of cases are operated on at the old surgical site—and the rest are operated on at the adjacent location above and below the old surgical area. The new surgical location is in the L34–L51 area, accounting for more than 70%, mainly using interlaminal approach, as the damage is located primarily in the lateral recess or the center of the spinal canal. Regarding the nature of the new pain generators, 83.3% were disc herniations or compression lesions that were not sufficiently decompressed. Notably, 16.7% of cases were compression due to surgical materials (disc graft, cement fragment in the spinal canal).

2. Foraminal Decompression

In this study, 3 patients had symptomatic foraminal stenosis causing radiculopathy. Preoperative imaging studies did not show any sign of instability. However, unilateral foraminal stenosis was diagnosed (Figure 1). The preoperative VAS score on the side of radicular pain was 7.3±0.6, the VAS score of back pain was 2.3±0.6, and the preoperative ODI of 54.0±8.1 shows that these patients were severely disabled. All of them underwent endoscopic foraminotomies. At an average follow-up time of 16 months, the average VAS score for leg pain was significantly changed to 2.7±0.6. One patient still had postoperative paresthesias (Table 1).

3. Posterior Decompression

For 21 patients who suffered from lateral stenosis or central stenosis at the same or adjacent level. Patients reported preop-

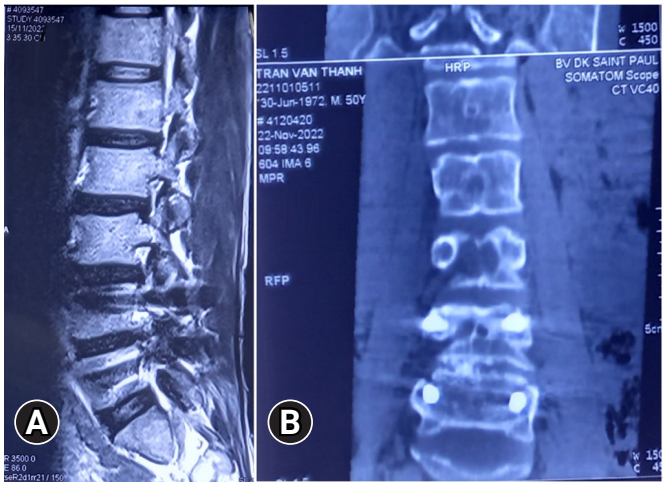

Figure 1. (A) An example of unilateral foraminal stenosis at the fusion segment. A sagittal T2-weighted magnetic resonance imaging shows an additional foraminal disc bulge causing exiting nerve root compromise. (B) Preoperative coronal reconstruction of a fusion segment with low disc height resulting in foraminal stenosis.

erative leg VAS of 7.1±0.7, back VAS of 2.6±0.6, and an ODI of 58.0±9.0 (Table 1). We performed the full-endoscopic procedure via a posterior approach to the previous level with the patient in the prone position under general anesthesia with mild flexion of the lumbar spine. The puncture site was confirmed using fluoroscopy in the anteroposterior and lateral views. Anatomical bony landmarks were located based on the preoperative 3-dimensional CT scan because, in most cases, the laminae were removed in the previous surgery. We performed a 7-mm incision by opening the fascia and inserting the dilator and working cannula, always watching for bone contact nearest the target point to decompress. In case of difficulty in finding the bony contact, we changed to watch for the superior edge of the screw, then followed the screw deeper by bipolar cautery and micropunch to remove soft tissues and visualize the bony tissue. We will check our location by C-arm again on anteroposterior and lateral view to determine whether we have reached the decompress point. Next to it, we exposed the medial margin of the bony area by a blunt dissector and then started to drill with the diamond burr at the point 3 mm away from the medial margin until we could see the inner cortical bone. Opening the epidural space by Kerrison punch where it was still intact, then from this location we dissected medially to find out the compromised nerve root by bipolar cautery and blunt dissector. If there were any adhesion ligament or disc material remnants, they would be removed with a micro punch and grasper. Finally, we check the nerve pulsation for full decompressing and finish the surgery. Endoscopic decompression resulted in an average reduction of VAS by 4 for leg pain at 06 months follow-up, but the backpain VAS score remained unchanged (2.2±0.5) (Figure 2).

Table 1. Characteristics of the failed back surgery syndrome patient group

Characteristic	Value
Age (yr)	61±15
Male sex	12 (50.0)
Previous surgery	
Endoscopy	3 (12.5)
Microscope	1 (4.2)
Open decompression, no fusion	4 (16.7)
Decompresion and fusion	12 (50.0)
Vertebroplasty	4 (16.7)
Location of the new pain generators	
Same level	14 (58.3)
Upper level	7 (29.2)
Lower level	3 (12.5)
Characteristics of pain generators	
Discal material	12 (50.0)
Bony spurs	8 (33.3)
Instrumentational material	4 (16.7)
Surgical level	
T10–11	1 (4.2)
L1–2	1 (4.2)
L2–3	3 (12.5)
L3–4	6 (25.0)
L4–5	7 (29.2)
L5–1	4 (16.7)
2 Levels	2 (8.3)
Axial location of compression point	
Foraminal stenosis	3 (12.5)
Lateral recess stenosis	13 (54.2)
Central spinal stenosis	8 (33.4)
Surgical approach	
Lateral approach (local anesthesia)	3 (12.5)
Posterior approach (general anesthesia)	21 (87.5)
Complications	1 (4.2)
Follow-up time (mo)	16±10
Operating time (min)	94±37

Values are presented as mean±standard deviation or number (%).

4. Decompression for the Interbody Cage Retropulsion

A 67-year-old man who had undergone an L2–S1 TLIF 10 months previously presented with left-side posterolateral thigh and calf pain. He also had right-side extensor hallucis longus weakness (3/5 strength on examination). Preoperative imaging showed that the L5–S1 interbody cage was displaced posteriorly. That caused very severe lateral recess stenosis (Figure 3). The patient underwent an endoscopic interlaminar removal

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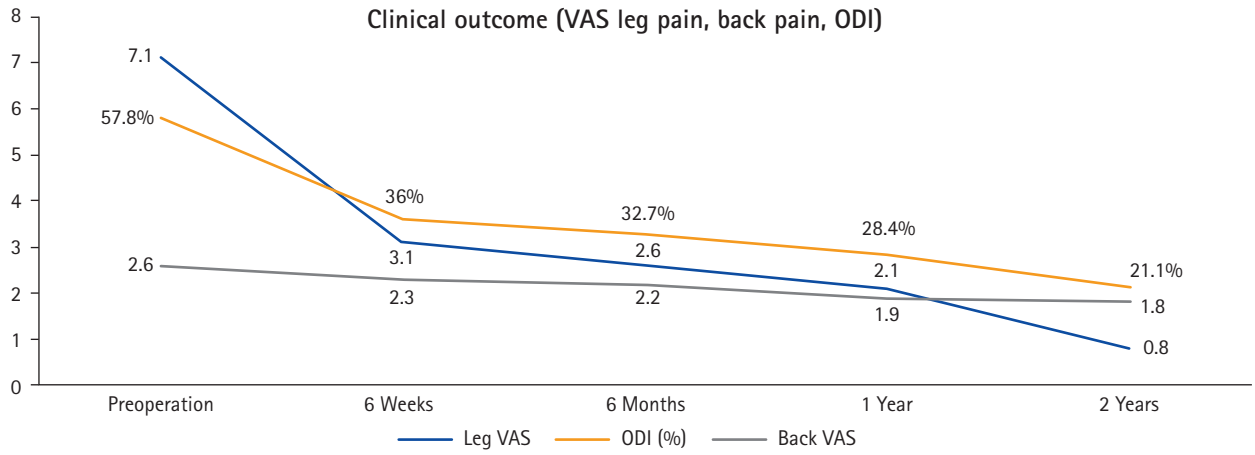

Figure 2. Clinical outcomes, showing visual analogue scale (VAS) scores for leg and back pain preoperatively and at 6-week, 6-month, 1-year, and 2-year follow-up, as well as the Oswestry Disability Index (ODI) preoperatively and at 6 weeks, 6 months, 1 years, and 2 years postoperatively. The VAS of leg pain and ODI scores improved significantly, with a statistically significant difference between the preoperative measurements and the values obtained at the last visit (p=0.01), but the VAS score of back pain did not change to a statistically significant extent.

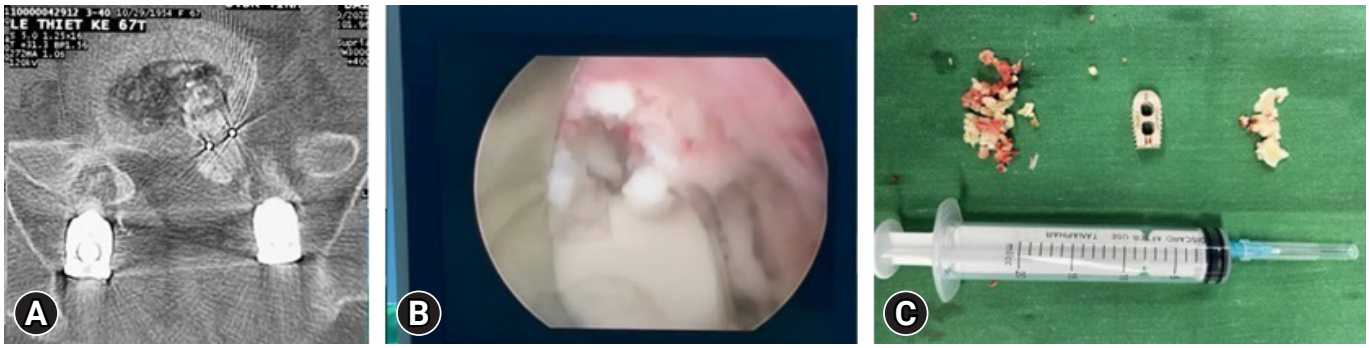

Figure 3. Instance of Interbody cage retropulsion. (A) An axial computed tomography image confirms the retropulsion cage. (B) An intraoperative image reveals cage dislodgement, disc material remnants, and a compressed S1-transversing nerve root. (C) Cage, disc material remnants, and prepared bone graft.

of the interbody cage and bone graft. However, after removing the cage, the surgeon performed in-situ fusion without adding enough bone graft to improve stability and bone healing. Consequently, the patient resulted in complications, and they had to undergo another surgery to replace the new disc graft and interbody fusion.

According to the improved MacNab classification, the proportion of FBSS patients with excellent results after endoscopic surgery is 33.3% and good is 41.7%, so the total rate of good and excellent status is 75% (Figure 4). In addition, there were 2 cases (6.3%) with poor results, including 1 case of compression due to a disc graft and 1 case of cauda equina syndrome with paraplegia before the first surgery. However, the majority of the first decompression was not extensive enough, so the patient's symptoms did not improve and were even worse than before surgery.

DISCUSSION

The number of patients undergoing spinal surgery, especially cement injection and spinal fusion, is increasing in other countries and also in Vietnam. With the number growing every day and the age of patients with the disease increasing, in addition to older patients with many different underlying conditions, it is clear that there is a high rate of complications during surgery. Not only that, according to the medical literature, there are more and more reports related to the increased rate of re-surgical instrumentation for cases of spinal fixation surgery, with some studies showing that this rate ranges from 10% to 29% [6].

In order to effectively treat FBSS, it is crucial for clinicians to understand the multifactorial etiology of postsurgical spine syndrome, which is categorized into preoperative, operative,

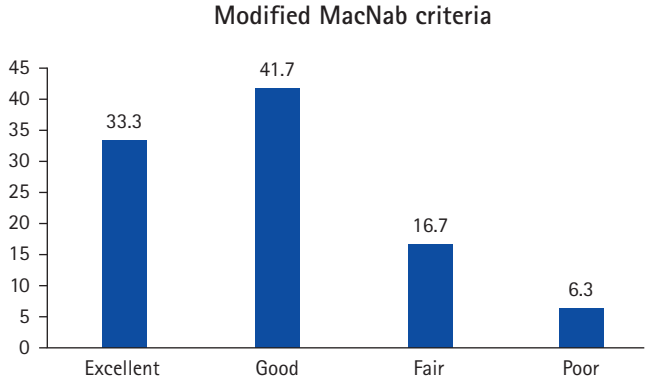

Figure 4. General outcomes of failed back surgery syndrome patients after fully endoscopic surgery.

and postoperative factors, as noted by Sebaaly et al. [2]. A spine surgery can fail due to various reasons, such as patient-related factors, poor candidate selection, inadequate decompression, instability, and more. However, before considering surgical intervention, conservative treatments such as pharmacologic, physical, and cognitive behavioral therapy, as well as injections, should be explored [7]. The goal of conservative treatment is to avoid the need for revision surgery and to identify the pain generators via injections. Although spinal cord stimulation trials have shown short-term pain relief, they are not without their own challenges, such as complications, infections, and loss of therapeutic effect [7]. Additionally, this treatment is not available in low-income countries like Vietnam. In our series, we first treated all patients conservatively, with at least 2 selective nerve infiltrations under CT guidance to accurately identify the pain generator before considering operative interventions such as opening and endoscopic surgery.

Opening resurgery for FBSS patients carries the potential risk of serious complications such as nerve damage, dura mater tear, delayed wound healing, infection, adjacent laminar degeneration, bone nonunion, bleeding, and many other complications [5]. For the above reasons, the minimally invasive nature, precise access, and effectiveness of endoscopic surgery are necessary in treating patients with FBSS, especially elderly patients. Even if performed under local anesthesia, the risk of strokes—complications arising during and after general anesthesia—can be reduced [8].

Endoscopic surgery is often considered impossible through the traditional posterior approach due to the axilla or hidden zone of MacNab and scar tissue adhesion [2,4]. However, recent studies have shown that endoscopic surgery via posterior or lateral approach can also access this zone with great success [6,7]. Compared to revision opening surgery, endoscopic surgeries are more beneficial in terms of reduced bleeding, lower risk of infection, and less soft tissue trauma. Although endoscopic surgeries require a steep learning curve, experienced physicians can perform them with minimal risk of serious complications such as dural tear, infection, or hematoma [7].

At Saint Paul General Hospital, FESS is performed with local anesthesia (with 3 patients having lateral approach) and general anesthesia in treating FBSS patients. Although it is a very minimally invasive surgery, FESS still requires precise manipulation, careful identification, and gentle dissection of anatomical structures to avoid damaging essential nerve structures in the fibrous adhesion of the old surgical site. Thanks to mastering the technique, the ratio of patients having their nerves released from compressive factors brings relatively positive results. It is equivalent to another report by authors Ahn et al. [3] and McGrath et al. [6]. To supplement the above comments, we present a case (Figure 2) of the exiting L5 nerve root being compressed by a hypertrophic superior articular process in the left L5–S1 foramen in a 74-year-old female patient with a history of cardiovascular disease, diabetes, and 3 previous spinal surgeries. The surgeon used a 10-mm operating tube through the contralateral interlaminar approach to expand the suitable interlaminar space then completely isolating and removing the left superior articular process tip from the L5 nerve root (Figure 5). The surgery gave excellent results, but a more significant number of patients and a more extended follow-up period are needed to provide long-term results.

Endoscopic operations have been shown to provide high levels of patient satisfaction, with many studies reporting significant improvements in pain and disability. For instance, the research of Kim et al. [9] demonstrated good clinical outcomes with an 80% reduction in pain. Similarly, the study of Cao et al. [10] showed that 11 patients who underwent interlaminar endoscopic decompression experienced significantly improved sciatica pain and ODI scores postoperation. In a study of 65 elderly patients with comorbidities, health-related quality of life improved after endoscopic surgery, even though they still experienced back pain [11]. While all our patients still experienced nonstatistically significant low back pain, 75% reported a good or excellent clinical outcome. These findings are consistent with other studies that have shown the alleviation of pain and disability among patients ranging from 16 to 86 years of age. Overall, these studies suggest that endoscopic surgery is an effective and safe option for patients looking to improve their quality of life by reducing pain and disability [3,4,12] .

In addition to the group of patients with FBSS, we also encountered patients with adjacent segmental disease causing

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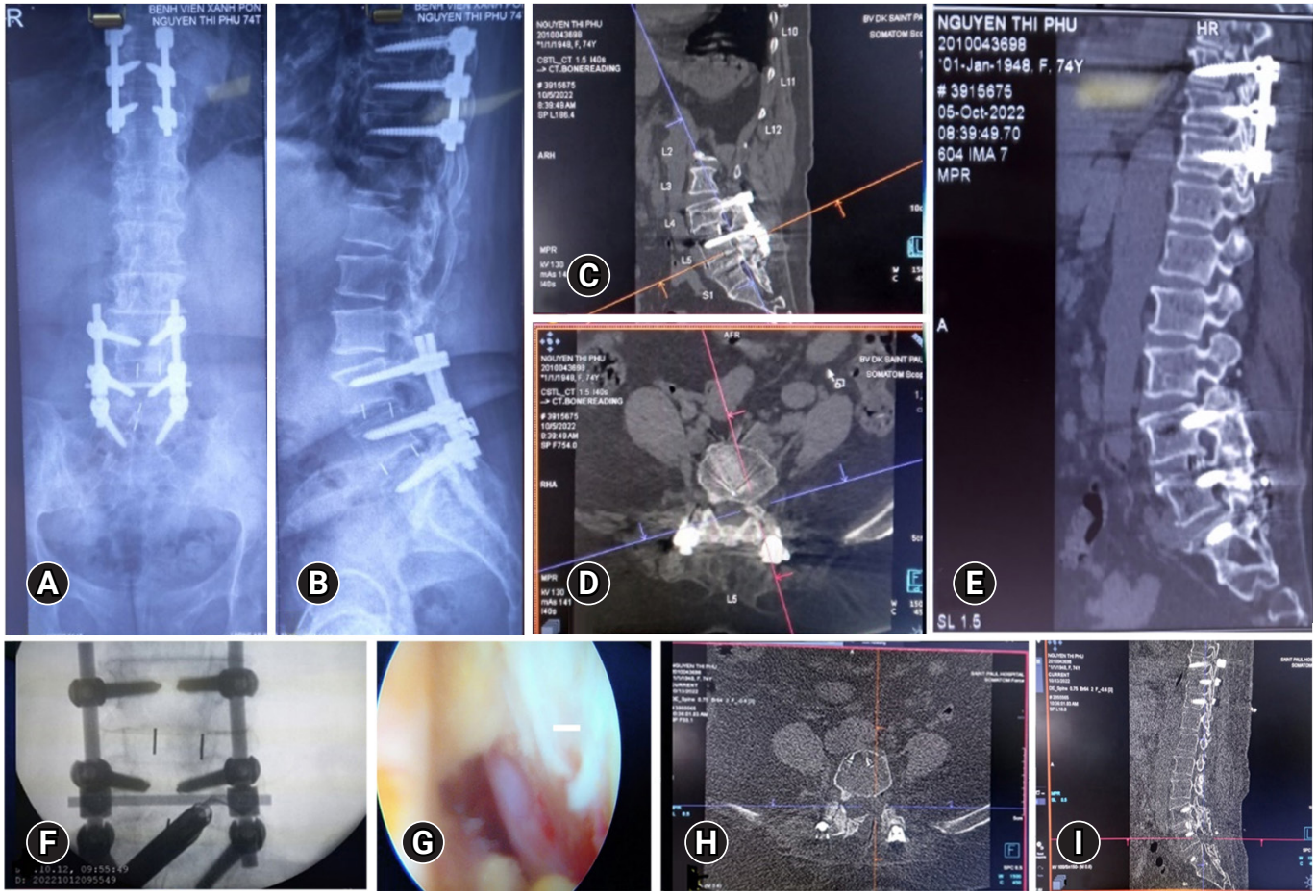

Figure 5. In a patient with failed back surgery sundrome, after L4-L5-S1 fusion, the hypertrophic superior articular process (SAP) of S1 compressed the L5 root and lateral recess on the left side. (A, B) Preoperative anteroposterior view of the lumbar spine. (C, D, E) Preoperative computed tomography (CT) confirmed left-side L5–S1 foraminal and lateral recess stenosis caused by the hypertrophic SAP of S1. (F) A C-arm examination showed a contralateral interlaminar approach to the L5–S1 left foramen. (G) The L5 exiting nerve root and dural matter were well decompressed after SAP tip removal. (H, I) A postoperative CT scan showed a well-decompressed lateral recess and foramen on axial and sagittal views.

narrowed foraminal, narrowed lateral recess, or even spinal canal stenosis. None of the 10 patients with adjacent segmental disease who had FESS needed fusion surgery during the follow-up period. We are referring to performing fusion in the adjacent segment because it is due to subsequent spinal degeneration causing nerve compression, even accompanied by spinal instability and global spinal imbalance. Therefore, evaluated preoperative inaccuracies about instability may lead to failure and cause the patient to need fusion surgery to the adjacent segments (even after endoscopic decompression surgery). When the patient shows no or very little back pain, accompanied by signs of disc height loss, many bony spurs around the disc or joint detected on CT, are signs of the stable condition of the adjacent disc level. However, determining the stability of the degenerative spine in adults is still controversial, with no genuinely accurate and precise standards yet [13]. Therefore, more future research is needed on the issue of determining the stability and instability of the spine based on clinical and imaging criteria to select appropriate patients to carry out immediate spinal stabilization instead of simple endoscopic decompression—potential risk of instability later [6].

Thus, endoscopic surgery is an effective approach to accessing fibrosis scar tissue in patients with FBSS. It plays a crucial role in treating this condition. This surgical technique allows for direct and clear visualization of compromised nerve roots. Endoscopic dissectors and radiofrequency cautery can be used to remove most of the scar tissue. This results in decompression of the nerve and resolution of pain, motor, and sensory dysfunction without causing spinal instability.

The patient group in our study was small in number and heterogeneous. The patient's previous surgery included many types: endoscopy, microsurgery, open decompression surgery,

spinal fixation, and cement injection. Therefore, the study results have many confounding factors. In addition, this is a retrospective study, so there needs to be more data from the control group for comparison. We realize there is a need for more studies with a standard design, randomized controlled, to evaluate the results and effectiveness of this method. However, the obtained results also demonstrate the feasibility of unilateral endoscopic spine surgery in treating FBSS as an alternative to major surgery.

CONCLUSION

Patients with FBSS face significant risks when reoperated using the classic open surgery method. FESS may be a safe and highly effective alternative in carefully selected patients.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Full-Endoscopic Discectomy and Debridement for Iatrogenic Spondylodiscitis After a Lumbar Peritoneal Shunt

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Lumbar peritoneal shunt (LPS) is the standard treatment for nonobstructive hydrocephalus. Shunt infection, overdrainage, bleeding, and cerebrospinal fluid leaks have been reported as LPS complications. We present a 70-year-old man who developed iatrogenic spondylodiscitis 2 weeks after LPS placement, experiencing severe back pain and neurological deficits. Despite the empiric antibiotics, his symptoms persisted. The patient underwent fully endoscopic debridement and drainage (FEDD) to address the infection without LPS removal. After the procedure, the patient experienced a significant reduction in pain. Even though pathogen cultures were negative, the empiric antibiotic treatment continued for 6 full weeks. The patient was able to ambulate with a thoracolumbar orthosis due to the lumbar kyphotic deformity. FEDD, in conjunction with effective antibiotics, offers rapid pain relief and functional improvement in iatrogenic spondylodiscitis, even with LPS placement. However, FEDD may not correct spinal deformities and is unsuitable for advanced spinal disease or instability. Early detection of spondylodiscitis is crucial for improved outcomes.

Key Words: Iatrogenic disease, Cerebrospinal fluid shunts, Lumbar vertebrae, Discitis, Endoscopy, Debridement

INTRODUCTION

Lumbar peritoneal shunt (LPS) is an effective and commonly seen treatment for nonobstructive hydrocephalus [1,2]. There are reported complications such as shunt infection, overdrainage, bleeding, and cerebrospinal fluid (CSF) leak [2]. However, iatrogenic spondylodiscitis after LPS has never been reported as a complication of LPS.

Iatrogenic spondylodiscitis is rare but fatal where it involves the infection and inflammation of the intervertebral discs and adjacent vertebrae after lumbar surgery or following invasive diagnostic or therapeutic procedures [3-5]. The diagnosis of spinal infections is often challenging due to their insidious onset with nonspecific signs and symptoms [6]. The diagnosis usually depends on the patient's symptoms and signs, imaging studies such as x-rays and magnetic resonance imaging (MRI), as well as laboratory tests like erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) [6]. A computed tomography (CT)-guided biopsy helps for establishing a bacterial diagnosis, and it allows tailoring antibiotic treatment [6,7]. However, studies suggest that the positive rate for culture is relatively low, and the outcomes for both culture-positive and culture-negative cases were similar in terms of antibiotic treatment [7].

It tends to occur in a population such as elderly and immunocompromised patients, and it is due to hematogenous spread of infection from other organs or direct extension of

infection following surgery, lumbar puncture, trauma, or local infection [4,5].

Conservative treatment with antibiotics and bed rest could be sufficient for mild infections [8,9]. A surgical procedure could be indicated when advanced bone destruction, progressive deformity, severe neurological deficit, or progressive infection occur [10]. LPS removal is also considered if there is a shunt infection or if the infection progresses [11]. Here, we present a 70-year-old male with iatrogenic spondylodiscitis after LPS placement. The patient underwent empiric antibiotic therapy for 3 weeks and underwent full-endoscopic debridement and drainage (FEDD) without removing the LPS due to sustainable back pain with neurological deficits.

CASE REPORT

A 70-year-old male patient with a history of prostate adenocarcinoma treated with radiotherapy also has Parkinson's disease, managed with oral medication. This time, he was newly diagnosed as normal pressure hydrocephalus (NPH) 6 months ago from the symptoms, brain MRI, and the CSF tap test [12]. This time, he went through LPS placement due to diagnosed NPH. Two weeks later, the patient developed progressive acute low back pain with a throbbing quality of 8 out of 10 on the pain scale, worsened by spine extension and flexion. He also complained of bilateral leg weakness, mostly severe over extension of the right thigh with numbness over right L4 dermatome, leading to difficulty ambulating.

A lumbar MRI confirmed the presence of acute inflammatory changes, edema, and annulus ruptures in the L3–4 disc, which were primarily compressing the right L3–4 lateral recess. The spinal catheter for LPS could be notified just at the L3–4 level (Figure 1A and B). The initial white blood cell (WBC) count, ESR, and CRP were within the normal range. However, the lumbar MRI suggests ongoing inflammatory processes suspected for spondylodiscitis. A CT-guided biopsy for bacteriological culture was suggested, but the patient refused. Since then, empiric antibiotic treatment has been initiated. Three weeks later, WBC count, CRP, and ESR had elevated with persistent severe back pain and the right leg pain. He exhibited no symptoms or signs indicative of meningitis, pneumonia, urinary tract infection, infective endocarditis, or surgical site infections. Pathogens were not detected in the blood, sputum, urine, or during tapping of the LPS shunt. CSF analysis from the shunt tapping showed no signs of infection. Considering the spinal catheter at the level of L3–4 through which the puncture was made, iatrogenic spondylodiscitis without LPS infection was considered. Subsequently, after discussing with the patient, FEDD was arranged, aiming for improving his back pain and the neurological function.

SURGICAL PROCEDURE

1.Patient Positioning and Skin Marking

The procedure was performed under local anesthesia and the patient was aware of each step of the procedure. After he was placed in a prone position on the radiolucent table, the entry point was determined to be about 10 cm from the midline. The trajectory line towards the base of the superior articular process (SAP) was drawn on the skin, obtained from anterior-posterior (AP) and lateral fluoroscopy.

2. Needle Puncturing and Working Cannula Docking

After determination of the entry point, an 8-mm stab incision is made through the skin and the fascia using the No. 15 blade after injecting 1% lidocaine subcutaneously. Subsequently, a cannulated needle is inserted from the entry point. 1% lidocaine was infiltrated into the muscle and the fascia along the trajectory towards the SAP. Following the tip of the cannulated needle docked on the base of the SAP confirmed by AP and lateral fluoroscopy, 0.25% diluted lidocaine was infiltrated to avoid excessive pain from the sequential manipulation [13]. A guide wire was then introduced through the cannulated needle, the sequential dilator was used to create the track for the working cannula. The working cannula was introduced and the tip of the working channel was docked at the base of SAP. After it's confirmed by the fluoroscopy, the working channel was rotated 90° gently to retract the exiting nerve away.

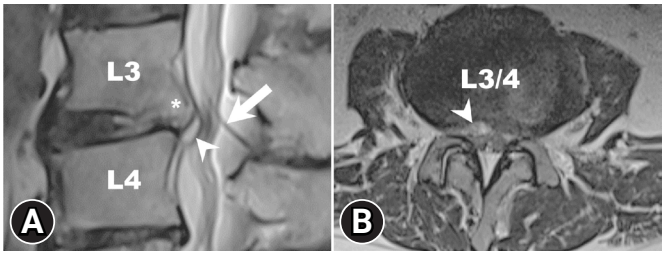

Figure 1. Lumbar magnetic resonance imaging (MRI) was performed 2 weeks after lumbar peritoneal shunt (LPS) placement. (A) Sagittal T2-weighted MRI shows acute inflammatory changes with edema (arrowhead) and annulus ruptures of the L3/L4 disc (star), with the visible spinal catheter of LPS (arrow) situated at the infection site. (B) Axial T2-weighted MRI image shows the L3/4 intervertebral disc compressing the right lateral recess (arrowhead).

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3. Full-Endoscopic Debridement and Drainage

The endoscope with 4.3-mm working channel (SPINENDOS GmbH, Munich, Germany) is introduced through the working channel, accompanied by continuous sterile saline irrigation. The radiofrequency coagulator (VANTAGE BIOTECH CO., LTD., Taoyuan, Taiwan) and grasping forceps were employed to dissect soft tissue under direct endoscopic visualization. Additionally, a high-speed diamond burr (SPINENDOS GmbH) is utilized to widen the working space in the foramen's ventral portion [14]. Once the position of the working cannula is adjusted into the epidural space, the inflamed disc and the granulation tissue with compressing the L4 traversing nerve was identified (Figure 2A and B), and attentive debridement was performed to remove the infectious disc and the granulation tissue. During the procedure, the radiofrequency bipolar probe was used to control hemostasis.

4. Final Check Point

As both the patient and the surgeon could mutually communicate during the procedure, the patient expressed the immediate right leg pain relief after removing the inflamed disc and the granulation tissue. After ensuring no other remaining pathology, we set the drain into the disc space and fixed on the back of the skin (Figure 2C and D). The surgical wound was closed with a single 3-0 nylon stitch.

5. Result

The patient experienced a significant reduction in back and leg pain. An MRI performed 3 days postoperatively showed decompression of the spinal canal at the level of L3–4 without compression of the right lateral recess (Figure 3A). However, focal irregular erosive changes are observed in the L3–4 spinal segment, resulting in a reduction in intervertebral space and apposition of the endplates (Figure 3B). The visual analogue scale (VAS) for back and bilateral leg pain decreased significantly from 10 to 5 immediately after the procedure in the sitting position (Figure 4C). The culture from the disc did not show any pathogen, the empiric antibiotic treatment was continued for the full 6-week course of the treatment. WBC count, CRP, and ESR showed significant reduction after the postoperative 1-week follow-up (Figure 4A and B). After 3 weeks postoperatively, the VAS score for the back and leg was 2 out of 10 (Figure 4C). The pathology report revealed neutrophilic infiltrate with fibrin exudate and granulation tissue in cartilage of the L3–4 disc (Figure 5A and B). Postoperative 6-month follow-up, the lumbar x-ray showed the lumbar kyphotic deformity (Figure 6). Ambulation was possible with the thoracolumbar orthosis.

DISCUSSION

LPS is a generally used modality to treat for the communi-

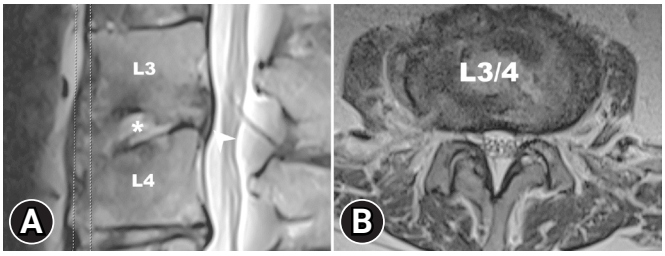

Figure 3. Postoperative 3-day lumbar magnetic resonance imaging (MRI). (A) Sagittal T2-weighted MRI shows decompression of the spinal canal, disappearance of annulus ruptures of the L3/4 disc, and acute inflammatory changes with edema (arrowhead) Irregular focal erosive changes (star) can be observed in the L3/4 spinal segment, leading to a reduction in the intervertebral space and the apposition of the endplates. (B) Axial T2-weighted MRI shows decompression of the right lateral recess.

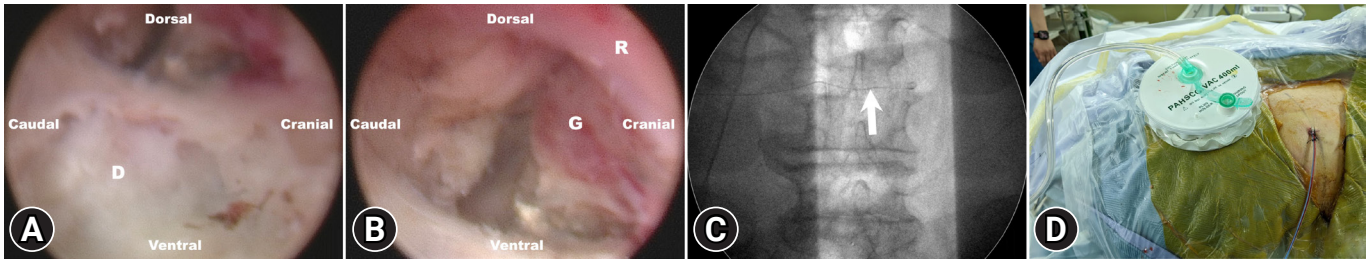

Figure 2. Vision under endoscopy. (A) Acutely inflamed annulus ruptures of the L3/L4 intervertebral disc are seen under endoscopic vision. (B) The epidural granulation tissue is compressing the traversing nerve root. (C) Placement of drainage (arrow) under fluoroscopic guidance. (D) The drainage is fixed on the back of the skin. D, intervertebral disc; G, epidural granulation tissue; R, traversing nerve root.

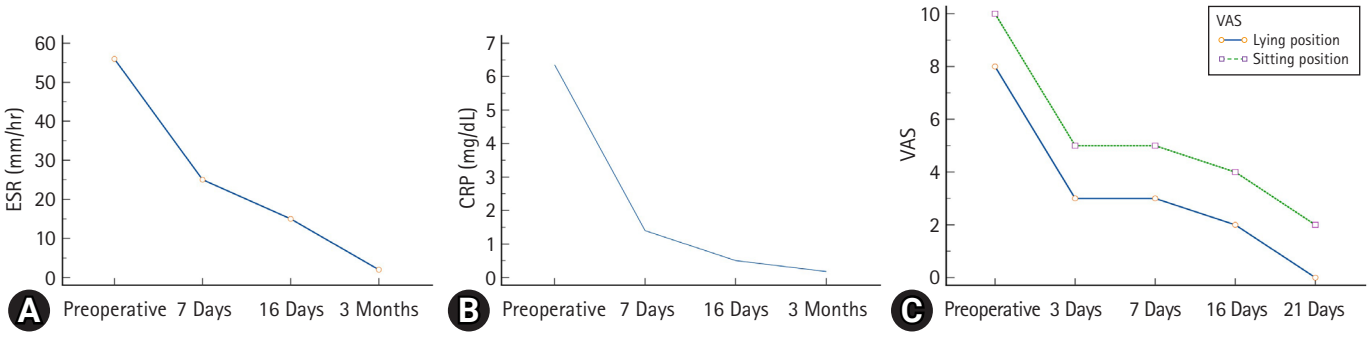

Figure 4. Laboratory data and the visual analogue scale (VAS) score of the patient. The erythrocyte sedimentation rate (ESR, A) and C-reactive protein (CRP, B) levels significantly decreased immediately after fully endoscopic debridement and drainage (FEDD). (C) The VAS score revealed that pain significantly improved right after FEDD.

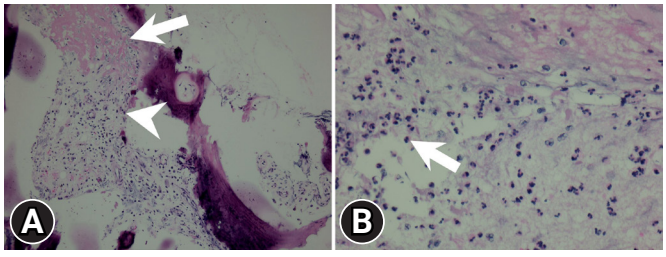

Figure 5. Pathology report of the intervertebral disc. (A) Neutrophilic infiltrate is seen in the cartilage (arrow) and in the intervertebral disc (arrowhead). (B) Epidural granulation tissue and mild neutrophilic infiltration with fibrin exudate (arrow).

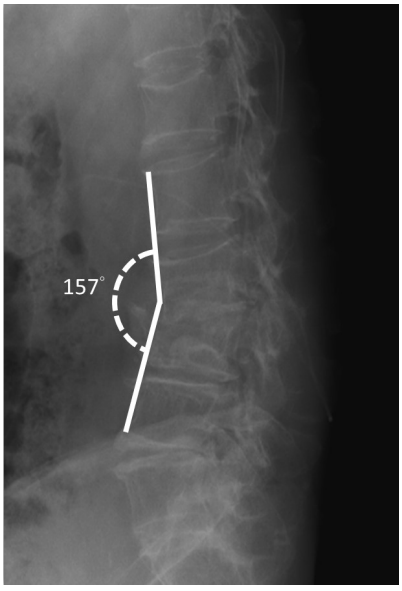

Figure 6. Postoperative 6 months lateral view of a lumbar x-ray. A lumbar kyphotic deformity of 157° was seen.

cating hydrocephalus [1,2]. Although it's known to be safe and effective, there are various kinds of complications reported such as malfunction, shunt infection, overdrainage, catheter migration, back pain, and radiculopathy [15,16]. Back pain has been reported up to 10% in the pediatric population, but it's little reported in the adult population [16]. To our best knowledge, this is the first case reported iatrogenic spondylodiscitis with the formation of granulation tissue after LSP placement.

The diagnosis of spondylodiscitis would be delayed due to the insidious onset of the disease [17]. Once it's diagnosed, early intervention is essential in the treatment of spondylodiscitis to prevent further damage to the spine [18]. Conservative therapy with antibiotics and pain management can help control the infection and reduce pain. An operative intervention is required if there is progressive neurological dysfunction, structural alignment, or infection even after the conservative measures [10].

In the present case, spondylodiscitis was observed in the lumbar MRI 2 weeks after the LPS placement, with no initial increase in WBC count, ESR, or CRP. A CT-guided biopsy for bacteriological culture was suggested to tailor antibiotic treatment [7]. However, considering the relatively high false-negative rates and the similar outcomes from antibiotic treatment, whether it is culture-positive or not [7], the patient hesitated. Despite empirical antibiotic treatment, the symptoms and signs persisted with elevated WBC counts, ESR, and CRP levels (Figure 4A and B). The increased values of these laboratory data support the idea of an ongoing infection in the spine. The pathogen detection from FEDD is relatively higher compared to CT-guided biopsy [10,19]. However, the absence of a detected pathogen in this case may be attributed to several factors: (1) Empiric antibiotic treatment administered before culturing the disc space, and (2) It could be a result of aseptic forms of spondylodiscitis, characterized by inflammation without any bacterial infection.

Pathologic reports showed neutrophilic infiltration with fi-

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brin exudate and granulation tissue formation in the cartilage of the L3–4 disc supports the idea of ongoing bacterial infection and inflammation (Figure 5A and B).

Immunocompromised patients (diabetes mellitus, malignancy, and acquired immunodeficiency syndrome), local and remote infections, previous lumbar puncture, previous spine trauma, and lumbar catheterization are the predisposing factors which would stratify the risk of spondylodiscitis [5]. In this case, prostate adenocarcinoma treated with radiotherapy was the predisposing factor.

Iatrogenic spondylodiscitis may be due to hematogenous spread, extension of the local infection, or direct inoculation of the pathogen [5]. Direct inoculation of the pathogen occupies 25%–30% [17,20,21]. Since the patient had no other infection sources such as meningitis, infective endocarditis, pneumonia, urinary tract infection, or local infection. Considering spondylodiscitis occurred at the L3–4 level, where the spinal puncture was made and the spinal catheter was placed, direct inoculation from LPS placement is the most likely possibility. One reported that the rate of spondylodiscitis increases with multiple attempts of lumbar puncture and epidural hematoma after the puncture [4]. Similar to lumbar puncture, as in our case, multiple attempts at spinal puncture for placing the spinal catheter for LPS also increase the risk of infection [4,22].

FEDD is a minimally invasive surgical technique performed through a small incision, eliminating the need for the extensive tissue dissection and muscle retraction often associated with traditional open surgical techniques, which may lead to higher complication rates with severe comorbidities [10,22,23]. FEDD is a safe and effective procedure. However, its application for iatrogenic spondylodiscitis with a foreign body has not been previously described. As FEDD is done under continuous water irrigation, the pathogen could spread into the epidural space and infect the shunt system. No serious complications, such as meningitis or LPS infection, occurred following FEDD, primarily due to the constant maintenance of water flow-in and flow-out during the procedure. Additionally, continuous irrigation of the pathogen throughout the process resulted in the immediate resolution of spondylodiscitis, leading to a rapid reduction in back and leg pain. This facilitated ambulation with a thoracolumbar spinal orthosis without any progression of the infection. The effective empiric antibiotic treatment also contributed to controlling the infection.

FEDD has already been demonstrated efficacy in treating spondylodiscitis, exhibiting high rates of infection control and favorable patient outcomes [10]. Nevertheless, it is essential to acknowledge certain limitations. FEDD cannot correct spinal deformities like in this case. Additionally, it may not be suitable for patients with advanced spinal disease, or significant spinal instability [23-25].

CONCLUSION

For patients diagnosed with iatrogenic spondylodiscitis with LPS, FEDD with effective antibiotic treatment could provide rapid pain relief and improve functional status. It would also be a relatively low-risk procedure that is suitable for elderly or immunocompromised patients. FEDD could not correct spinal deformities. Therefore, early detection of spondylodiscitis would be crucial for a favorable prognosis.

NOTES

Conflict of Interest

CMC, a member of the Editorial Board of Journal of Minimally Invasive Spine Surgery & Technique, is the author of this article. However, he played no role whatsoever in the editorial evaluation of this article or the decision to publish it. Author has no conflict of interest to declare.

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The Growing Trend of Degenerative Spine Surgery Under Spinal Anesthesia in the Elderly: Empowering Patient Safety: A Series of 83 Cases

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Objective: Awake spine surgery has improved patient outcomes in common orthopaedic procedures. Integrating it into spine surgery is of interest to surgeons since it may reduce the difficulties and complications associated with general anaesthesia. The demand for safe spine surgery is rising due to healthcare improvements and increasing ageing population. This study aimed to assess the safety and feasibility of spine surgery under spinal anesthesia for elderly patients aged 65 and older.

Methods: In a retrospective review, 83 lower lumbar spine surgeries performed under spinal anesthesia by a single surgeon at a single hospital from 2015 to 2019 were examined. All procedure-related data was collected prospectively for analysis. This study explored demographic characteristics, surgical features, perioperative concerns, and anesthesia-related obstacles in spine surgery under spinal anaesthesia.

Results: This study included 83 patients aged 65 years and older. Following follow-up, visual analogue scale and Oswestry Disability Index scores considerably improved ($p < 0.05$). Patients in the American Society of Anesthesiologists physical characteristics classification grade II had the highest count. The most common level was L4–5. About 7.2% of patients needed multiple spinal procedures. The average induction time was 20.2±9.6 minutes. The average intraoperative operation lasted 84.0±17.20 minutes. The shifting-out process took 7.95±2.10 minutes to start. The mean intraoperative arterial blood pressure was 70.7±10.8 mmHg, and the mean heart rate was 69.0±7.2 beats per minute. The average postoperative analgesia initiation time was 79.9±7.7 minutes. The average postoperative stay was 3.02±0.83 days. In 10.8% of individuals, cerebrospinal fluid was found. 1.2% of patients experienced postoperative hypotension, 12% experienced nausea and vomiting. Infection occurred in 2.4% of patients, and 14.5% experienced post-operative urinary retention.

Conclusion: This case series shows that older patients can undergo lumbar fusion, decompression surgeries under spinal anesthesia with a skilled anaesthesia team. Additionally, spinal anaesthesia substantially minimised dangers and concerns related with general aanaesthesia.

Key Words: Awake spine surgery, Geriatric, Spinal anesthesia, Lumbar spine, Fusions, Decompression

INTRODUCTION

With betterment in healthcare and increasing geriatric population in developing countries, the need and want to stay pain free has been increasing among this population group. The elderly demographic currently expresses a desire to lead a life free from pain, resulting in a rise in the frequency of lumbar spine decompression and fusion procedures [1]. The perceived risk associated with performing spine surgeries on the elderly population was mitigated in recent years due to advancements in anesthesia regimens. The efficacy of surgery in alleviating pain associated with spinal stenosis surpasses that of non-surgical therapy options [2,3]. Historically, awake surgery has been employed for craniotomies, although in recent years, there has been a growing prevalence of utilizing this technique for spine procedures as well [4].

A German surgeon named August bier used cocaine via lumbar puncture as the first person to ever give spinal anesthesia for spine surgery [5]. Even though there are cases of spinal anesthesia for spine surgery that date back to 1960s, eventually with the introduction of complex lumbar and long segment surgeries the complacency to general anesthesia started and eventually patients were not offered a choice of spinal anesthesia with general anesthesia becoming the standard. On the contrary to this, Lessing et al. [6] have described a 5-level lumbar fusion done under spinal anesthesia in a 72-year-old male successfully without any complications.

Many such studies in the recent past have been gaining much popularity as spine surgery is leaning towards minimally invasive techniques to decrease muscular stripping and provide patients with a much better outcome of which regional anesthesia has become a vital part.

General anesthesia is currently the standard followed in most centers for conducting spine surgery as literature gives us assurance of its safety. Spine surgery may require lengthy operative time due to unpredictability, and invasiveness of the procedure needing good airway control achieved only with general anesthesia. This is where minimally invasive surgery plays a huge role in changing the dynamics of how we perceive spine surgery from the surgeons and the anesthetist point of view. Many studies in the past have shown that the use of spinal anesthesia can reduce the use of vasopressors, need for transfusion, intraoperative hypotension and increase general hemodynamic stability in elderly patients with comorbidities, due to the lack of rostral spread of isobaric anesthetics to cardiac baroreceptors in spinal anesthesi [7,8]. Another aspect seen in the elderly population is the chances of postoperative delirium which are as high as 40% in general anesthesia, while it is hypothesized that spinal anesthesia decreases the chances of post operative delirium and dementia as it does not require deep sedative techniques [9].

Enhanced recovery after surgery (ERAS) is a novel concept that integrates perioperative and postoperative interventions aimed at facilitating expedited patient recovery and reducing the psychological and physiological burdens associated with surgical procedures, ultimately enhancing the overall patient experience. The ERAS protocol encompasses a range of multivariate procedures, such as preoperative education and counselling, preoperative optimization, smoking and alcohol cessation, pre-emptive analgesia, and various other aspects [10,11]. Another aspect of this protocol involves the utilization of regional or spinal anesthesia in spine surgeries.

Despite the advancements in ERAS protocols and the prevalent adoption of spinal anesthesia by orthopedic surgeons in lower limb and arthroplasty surgery, there persists a reluctance to employ these techniques in spine surgeries. The obstacles appear to be influenced more by the preferences of surgeons and the comfort levels of anesthetists, rather than being primarily rooted in scientific considerations. The lack of awareness and exposure to spinal anesthesia, in contemporary spine practice is evident due to the limited utilization of this method in spine surgeries and insufficient training among surgeon/anesthetist teams. Numerous prior research has demonstrated that spinal anesthesia yields superior outcomes compared to general anesthesia, as evidenced by diminished perioperative expenses, lower utilization of pain-related anesthesia, and decreased incidence of postoperative nausea and vomiting [7,12,13].

While numerous studies have been conducted on spinal anesthesia in the setting of the spine, there is a paucity of research specifically focused on geriatric population in this regard. This study presents an analysis of the experiences of 83 elderly patients who underwent lumbar spine procedures for degenerative spine pathologies causing compression as seen in lumbar canal stenosis or patients with disc pathologies, including both fusion and nonfusion procedures conducted under spinal anesthesia (given at 1 or 2 levels above the operative level). The study aims to investigate the potential advantages and risks associated with these surgeries by examining various perioperative and intraoperative outcomes.

MATERIALS AND METHODS

An analysis was conducted on a cohort of 85 patients who

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underwent lumbar spine surgery for degenerative spinal stenosis under spinal anesthesia at a single institute (Bombay Hospital and Medical Research Institute) by a single surgeon. The data used for this analysis consisted of longitudinal prospective follow-up data collected from the period of 2016 to 2020. The need for approval was waived off from the local ethics committee, specifically the Institutional Review Board. Informed consents were obtained from all patients for the procedures. Furthermore, the potential utilization of their data for subsequent research analysis was thoroughly elucidated to each individual. The treatment approach implemented in our study involved an initial phase of conservative therapy, which encompassed pain management strategies and the administration of epidural steroid injections, for a minimum duration of 6 months.

The study's inclusion criteria had a case series of individuals aged 65 years and older who exhibited symptomatic lumbar pathology, specifically mechanical low back pain and radiculopathy, claudication with or without neuro-deficit, involving less than 3 levels at the L3–4/L4–5/L5–S1 levels. These symptoms were attributed to a range of aetiologies, including degenerative, dysplastic, and isthmic spondylolisthesis, degenerative lumbar canal stenosis with instability, and prolapsed intervertebral disc. Patients with minimum follow-up period of 2 years were included in the study.

The exclusion criteria for this study consisted of individuals who needed revision spine surgery, those with infections, tumours, Cauda equina syndrome, individuals with back pain or radiculopathy caused by factors outside of the spine, individuals who needed surgery at higher lumbar levels (specifically L1–2), and patients with low Ejection fraction under 55% and those with a short follow-up period. The administration of anesthesia for all surgical procedures was overseen by a sole anaesthesiologist, utilizing a consistent anesthetic approach. The demographic parameters of the patients, including age, sex, and American Society of Anaesthesiologists (ASA) physical status, were recorded. Based on the established criteria for inclusion and exclusion, individuals who had counselling for surgery were included in the study. In accordance with the established criteria for the study, spinal anesthesia was given to all included participants. The participants received comprehensive counselling and were provided with a detailed explanation of the advantages and disadvantages connected with this approach. A total of 85 patients voluntarily agreed to undergo spinal anesthesia and met the predetermined criteria for inclusion in the study.

1. Anesthesia Technique

We employ spinal anesthesia, utilizing the sitting position for optimal administration. The selected vertebral spaces for the procedure include L2–3, L3–4, and L4–5, with the level of spinal anesthesia set at T8. For extended surgical durations, we may adjust the level to T6. The spinal drugs employed for this technique include bupivacaine 0.5%, levobupivacaine 0.5%, and ropivacaine 0.75%. To enhance the efficacy of spinal anesthesia, we incorporate additives such as Fentanyl (10–20 μg), Buprenorphine (60–80 μg), and Clonidine (15 μg).

Following the spinal anesthesia, the patient undergoes proning after 15 minutes, contributing to the effectiveness of the procedure. During the prone position, sedation is administered, typically involving the use of midazolam and Nalbuphine (Fortwin). This comprehensive approach ensures the patient's comfort and the success of the spinal anesthesia in our spine surgery protocol.

2. Operative Technique

The patients who underwent decompression or fusion surgeries were approached using a 2.5-cm paramedic incision, positioned 3–5 cm away from the midline on the side that exhibited more severe symptoms. The procedure of tubular decompression was performed using 22-mm tubes from the METRx system, manufactured by Medtronic (Minneapolis, MN, USA). This was done in conjunction with a partial unilateral or bilateral laminotomy (over the top), foraminotomy and inferior partial facetectomy, all of which were guided by microscopic visualisation. In situations necessitating interbody fusion, the procedure involved further inferior facetectomy, discectomy, preparation of the end plate, and insertion of a cage along with the utilization of autograft taken from the local region. Cannulated pedicle screws were introduced subsequent to the introduction of a guidewire through Cook's needle, followed by sequential tapping using dilators and a tap, all under the guidance of fluoroscopy (Figure 1). Rod was introduced to a device via a distinct proximal stab incision. A comprehensive wash was carried out, followed by sequential layering for closure. Upon the conclusion of the procedure, the patient was afterwards transported to the postanaesthesia care for the purpose of recovery.

The perioperative parameters that were assessed in this study included the duration of surgery, blood loss during surgery, time from entering the operating theatre to incision, occurrence of cerebrospinal fluid (CSF) leak during surgery due to dural

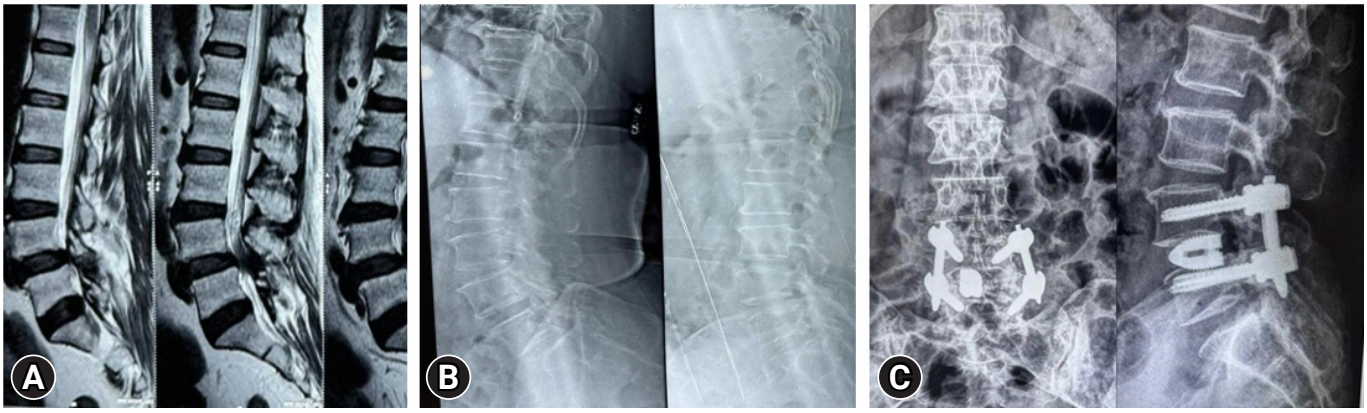

Figure 1. Case 1: a 68-year-old woman. (A) Preoperative sagittal section of magnetic resonance imaging. (B) Preoperative x-ray in lateral flexion and lateral extension. (C) Postoperative x-ray.

tear or dural needle prick, time from bandaging to exiting the operating theatre, need for postoperative analgesia, episodes of postoperative emesis, occurrence of urinary retention, postanaesthesia care unit (PACU) time, and duration of hospital stay. Postoperatively pain management was done using intravenous acetamiophen and tramadol for only first postoperatively and all patients were shifted to oral acetaminophen and tramadol if needed for a period of 5 days. These parameters were carefully documented, and the collected data was then extrapolated to evaluate the study's results. Postoperative complications were systematically recorded and categorised into general and neurological domains. General difficulties encompassed fever, wound infection, cardiac and pulmonary issues, as well as urinary tract infections. Neurological complications consisted of CSF leaks following surgery and the occurrence of neurological deficits.

RESULTS

A total of 85 patients were included in the study but 2 patients were lost to follow-up. Forty-one males (49.4%), 42 females (50.6%) were included in study aged from 66 to 75 years (70.4±4.1 years). Their body mass index ranged from 28 to 38 kg/m^2 (33.42±4.9 kg/m^2). Patients consuming alcohol were 19 (22.9%) whereas those who were chronic smokers were 17 (20.5%). Hypertension was amongst 41 patients (49.4%) and 30 (36.1%) were diabetic. The level of fusion done ranged from 37 (44.6%) that had L3–4, 69 (83.1%) had L4–5 whereas L5–S1 was seen in 16 (19.3%). All participants included in the study were followed-up for an average period of 12.8±0.9 months. The number of surgeries where fusion was carried out was 33 (39.8%, Table 1).

Table 1. Demographic characteristics of the included patients (n=83)

Parameter	Value
Sex	
Male	41 (49.4)
Female	42 (50.6)
Age (yr)	70.4 ± 4.1
Body mass index (kg/m^2)	33.4 ± 4.9
Alcohol consumption	19 (22.9)
Smoking	17 (20.5)
Hypertension	41 (49.4)
Diabetes	30 (36.1)
Follow-up period (mo)	12.8 ± 0.9
Level	
L3–4	37 (44.6)
L4–5	69 (83.1)
L5–S1	16 (19.3)
Surgical procedures	
Fusion	33 (39.8)
Decompression	50 (60.2)
American Society of Anesthesiologists grade	
Grade 1	4 (4.8)
Grade 2	48 (57.8)
Grade 3	29 (34.9)
Grade 4	2 (2.4)

Values are presented as number (%) or mean±standard deviation.

The ASA physical status classification grade was II ranging up to III (2.3±0.6). The requirement for a repeat spinal was in 6 patients (7.2%). Also, the induction time ranged from 10 to 30 minutes (20.2±9.6 minutes). Whereas the total operative time was 68 to 100 minutes (84.0±17.2 minutes). Time taken to leave the operative room was about 6 to 10 minutes (7.95±2.10 minutes). The total blood loss calculated was about 104 to 140 mL (124.3±19.6 mL). Estimated intra operative mean arterial blood pressure (MABP) was 60 to 80 mmHg (70.71±10.8 mmHg). The

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intraoperative heart rate recorded was around 62 to 75 beats per minute (69.0±7.2 beats). Average number of days (Table 2) for the postoperative stay was 2 to 4 days (3.02±0.83 days).

Complications were limited and varied from postoperative urinary retention that occurred in about 12 patients (14.5%). Followed by nausea and vomiting prevalent in 10 patients (12%). CSF from needle puncture which was seen in 9 patients (10.8%) which were all managed without any active intervention with water tight closure. Infection was limited to 2 patients (2.4%), both of which were staphylococcus aureus infections treated with intravenous/oral antibiotics alone (Table 3). Lastly, postoperative hypotension was seen only in 1 (1.2%).

Preoperative visual analogue scale (VAS) score was average mean of 7.31±0.78 which significantly reduced to be an average score of 2.86±0.68 (Table 4). ($p<0.05$) Similarly the Oswestry Disability Index (ODI) scoring reduced significantly post operatively to 26.39±4.08 which was 71.02±5.51 preoperatively ($p<0.05$, Figure 2).

Table 2. Perioperative parameters

Parameter	Value
Requirement for a repeated spinal procedure	6 (7.2)
Induction time (min)	20.20 ± 9.60
Total operative time (min)	84.00 ± 17.20
Single level (53 cases)	74.86 ± 5.94
Two levels (30 cases)	100.23 ± 18.78
Fusion (33 cases)	87.91 ± 18.50
Decompression (50 cases)	81.48 ± 16.04
Time to leave the OR (PACU) (min)	7.95 ± 2.10
Blood loss (mL)	
Average	124.30 ± 19.60
Single level (53 cases)	121.20 ± 15.26
Multiple levels (30 cases)	129.63 ± 24.97
Fusion (33 cases)	126.36 ± 19.76
Nonfusion (50 cases)	122.86 ± 19.60
Intraoperative MABP (mmHg)	70.71 ± 10.80
Intraoperative HR (beats per min)	69.00 ± 7.20
Time until the need for postoperative analgesia (min)	79.9 ± 7.70
Postoperative stay (day)	3.02 ± 0.83

Values are presented as number (%) or mean±standard deviation.
OR, operating room; PACU, postanesthesia care unit; MABP, mean arterial blood pressure; HR, heart rate.

DISCUSSION

In this study, we provide our findings of a cohort of 83 elderly individuals who underwent lumbar spine procedures, encompassing both fusion and nonfusion techniques. These interventions were performed using minimally invasive approaches under spinal anesthesia. Over a period of a decade performing lumbar spine surgeries in regional anesthesia our experience in the elderly population seems to be of utmost importance for literature. The study conducted exhibited an average operative time of 84.0±17.2 minutes. The existing literature requiring general anesthesia demonstrates consistent findings, with an average duration of approximately 100 minutes [14,15]. The VAS and ODI patterns at 6 months and 1year and final follow-up in our study significantly improved in comparison to preoperative values ($p<0.05$).

In contrast to the typical cohorts observed in previous studies, most of our patients exhibited ASA physical status classification grades II and III, indicating a higher level of risk. However, it is noteworthy that all the elderly patients underwent successful surgeries using spinal anesthesia. The average induction time for this procedure was a mere 20.2±9.6 minutes, and none of the patients necessitated a switch to general anesthesia. Another notable observation pertained to the duration of time required for all patients to be transferred from the observation area (PACU) following surgery. On average, this process took only 7.95±2.1 minutes. This expedited transfer can be attributed to the supplementary analgesic effects of spinal anesthesia during the postoperative phase, which ensured that all patients remained conscious, comfortable, and devoid of pain. A study conducted by Pierce et al. [16] similarly yields findings

Table 4. VAS and ODI comparison

Score	Preoperative	1-Year postoperative	p-value
VAS	7.31 ± 0.78	2.86 ± 0.68	< 0.001*
ODI	71.02 ± 5.51	26.39 ± 4.08	0.002*

Values are presented as mean±standard deviation.
VAS, visual analogue scale; ODI, Oswestry Disability Index.
*$p<0.05$, statistically significant differences.

Table 3. Complications (n=83)

Complication	Fusion	Decompression	Single level	Multiple levels	No. (%)
Cerebrospinal fluid from needle puncture	5	4	3	6	9 (10.8)
Postoperative hypotension	-	-	-	1	1 (1.2)
Nausea and vomiting	7	3	5	5	10 (12.0)
Infection	2	-	1	1	2 (2.4)
Postoperative urinary retention	8	4	5	7	12 (14.5)

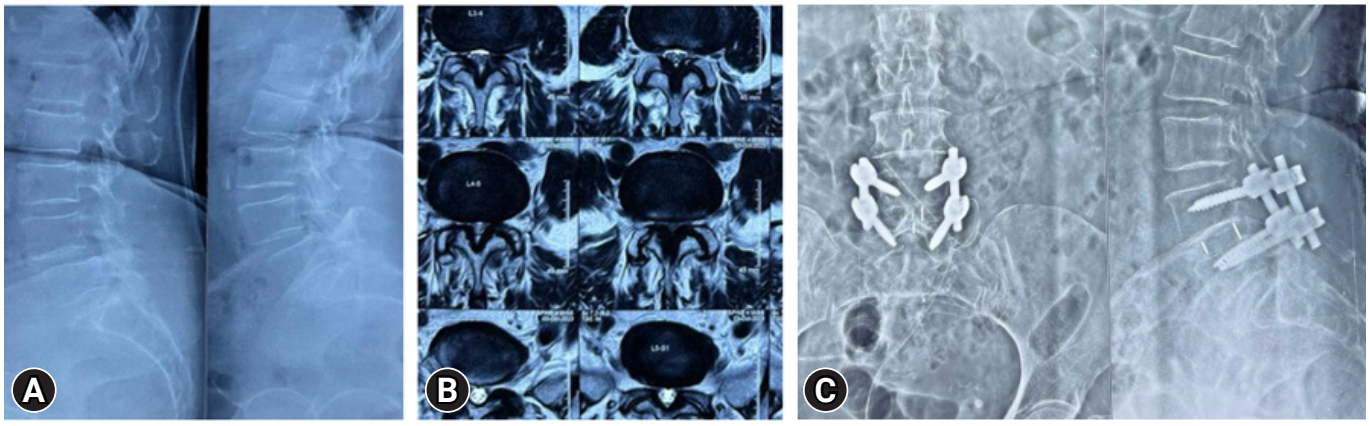

Figure 2. Case 2: a 74-year-old woman. (A) Preoperative x-ray in lateral flexion and lateral extension. (B) Preoperative axial section of magnetic resonance imaging. (C) Postoperative x-ray.

that are close to our own. Other studies which were done on younger population (<65 years), showed similar results with shorter hospital stay, well controlled pain and good patient satisfaction [17].

Regarding other perioperative complications, it was observed that 7.2% of cases required a repeat spinal procedure, while CSF puncture occurred was observed intraoperatively in 10.8% of instances. Notably, none of the patients exhibited symptomatic dural leak and all were managed conservatively with only water tight closure. During the postoperative phase, a mere 1.2% of patients exhibited symptoms of hypotension, while 6% of patients reported experiencing nausea and vomiting. A study done by McLain et al. [18] found a higher incidence of nausea and vomiting in patients who underwent procedure under general anesthesia in comparison to the regional anesthesia group. A comprehensive analysis conducted using a database approach investigated lumbar spine procedures, irrespective of the type of anesthesia employed, and revealed an aggregate incidence of adverse outcomes, including mortality at 16.34%, major complications at 3.23%, and mild complications at 14.57% [19]. According to review research conducted in 2008, it was found that the mortality rates among older individuals following spine procedures were around 10% [20]. Over the decade spine surgery has evolved into better and less invasive techniques to decrease mortality and in our cohort of study population we reported no major complications or mortality.

Regarding hemodynamic stability, the intraoperative MABP was consistently maintained at an average of 70.71±10.8 mmHg, with no observed significant fluctuations in any of the patients. The heart rate during the surgical procedure was also sustained at an average of 69.0±7.2 beats per minute. Prior research has also demonstrated that regional anesthesia exhibits significantly lower alterations in MABP and heart rate compared to general anesthesia [12,21]. In one observed case, the patient experienced bradycardia following prone positioning, which was attributed to the cranial spread of the administered drug. However, this adverse event can be mitigated by ensuring the adequacy of anesthesia level and employing appropriate head elevation techniques to minimize cranial spread. The average estimated blood loss was 124.3±19.6 mL. Additional research involving patients under the age of 65 and comparing general anesthesia with spinal anesthesia demonstrated comparable rates of complications in both groups, as well as minimal fluctuations in intraoperative MABP. However, patients who underwent spinal anesthesia experienced significantly fewer episodes of nausea [22]. According to existing literature, it has been suggested that spinal anesthesia patients experience a decrease in blood loss compared to patients under general anesthesia, primarily attributed to the reduced intrathoracic pressures resulting from spontaneous breathing.

Our study did show a considerably higher rate of post operative urinary retention in 12 patients (14.7%), out of which 4 patients required the use of bladder drainage using a K90 Catheter and the need for catheterization in 6 patients. These could also be attributed to the fact that in elderly population due to weakness in bladder mobility preoperatively due to lumbar spine compression or due to prostate hypertrophy seen in male patients. Studies comparing post operative urinary retention when compared in general and spinal anesthesia, there was a significantly more incidence in spinal anesthesia regarded due to the intrathecal spread in spinal anesthesia [23].

Another concern with regards to spinal anesthesia in our experience is the question whether spinal anesthesia is a viable option for procedures that may last up to 3 hours as the half-

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life of bupivacaine is 2.7 hours only. Such time related issues could be surgeon specific as different surgeons may require more time in some cases, but studies also report that anesthetic medications do exhibit pronounced and extended effects in geriatric population [20].

Another increasingly common strategy gaining attention is the utilization of epidural anesthesia for lumbar spine cases. This technique enhances the anesthesia effect by means of a catheter and can also be employed in the postoperative phase to effectively manage pain, thereby minimizing the requirement for narcotics. A study done on 111 patients who underwent lumbar spine procedures under epidural anesthesia with light sedation has been already shown to be a safe and feasible option of utilizing conscious sedation where patients can give live intraoperative feedback [24]. This study also shows that the use of epidural anesthesia with local anesthetics that have been diluted by half leads to effective pain relief while causing minimal impairment of motor function in the lower extremities. Conscious sedation is a surgical aid that resembles neuromonitoring. While neuromonitoring is not commonly employed in lumbar spine surgeries and the effects of spinal anesthesia on neuromonitoring are yet to be fully understood, previous studies have indicated that there is no notable disparity in neuromonitoring alterations when comparing patients who underwent surgery with balanced anesthesia versus total intravenous anesthesia [25].

In the context of performing spinal anesthesia for lumbar spine procedures, a crucial factor for ensuring patient safety is the presence of a proficient anesthesia team capable of promptly executing a supraglottic intubation procedure, as the potential for airway compromise is recognized when patients are positioned prone. Additional individuals at high risk include people who have severe cardiopulmonary dysfunction and those who suffer from obstructive sleep apnea. Numerous individuals experience discomfort when remaining awake and in a prone position throughout extended surgical procedures. Consequently, in such instances, the administration of mild sedation or, if desired by the patient, the implementation of general anesthesia, which is considered to be a safer alternative, may be warranted. In the context of younger patients, it is advisable to engage in a comprehensive discussion with the patient regarding the selection of anesthesia, by thoroughly considering the advantages and disadvantages, a collaborative decision can be reached, ultimately leading to potential benefits for the patient.

However, this study has several limitations. The present investigation comprised a limited group of patients who underwent a retrospective analysis. Hence, it is imperative to conduct a study including a larger cohort and employ a prospective analysis. In light of the encouraging findings and advantageous consequences demonstrated in our investigation pertaining to spinal anesthesia, it is crucial to undertake a comprehensive comparative analysis vis-à-vis general anesthesia in order to compare all perioperative variables and potential complications. Furthermore, this study did not investigate the efficacy of utilizing just epidural anesthesia for lumbar spine surgery. However, such an investigation is scheduled to be conducted in the future. Nevertheless, the importance of this research resides in its potential to enhance surgeon competency and promote the broad utilization of regional anesthesia for lumbar spine surgeries, therefore reducing the likelihood of complications. The objective of our study is to potentially enhance the feasibility of administering safe spinal anesthesia in the elderly population.

CONCLUSION

The utilization of spinal anesthesia has become prevalent in the younger demographic for spine procedures, yielding positive outcomes. Our study highlights that employing spinal anesthesia in minimally invasive spine surgery allows the geriatric population to undergo lumbar spine surgeries safely, with minimal occurrence of significant complications. The study has successfully established the viability, safety, and effectiveness of conducting lumbar spine procedures utilizing spinal anesthesia. Nevertheless, the significance persists in the preoperative and perioperative optimization of patients using multimodal methods, aiming to facilitate early mobilization and reduce morbidity in elderly patients.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Single-Stage Lateral Anterior-to-Psoas Interbody Fusion and Facet Screws as a Treatment for L5–S1 Adjacent Segment Disease in a Patient With a Long-Segment Construct

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Objective: Adjacent segment disease (ASD) occurs in 9% of patients with long-segment lumbar spine fusion and results from the transmission of a greater degree of stress to the segments cranial and caudal to a fused segment. The treatment of symptomatic ASD typically involves extending fusion to the involved segment. Revision and extension of posterior instrumentation bears the disadvantage of involving the exposure and modification of old hardware. Lateral interbody fusion cannot be performed at L5/S1 due to the iliac crest. Anterior lumbar interbody fusion typically still requires flipping the patient to augment the construct posteriorly. Here, we present a method to treat L5/S1 ASD using single-position anterior-to-psoas (ATP) interbody fusion combined with facet screw instrumentation.

Methods: An 80-year-old man, who had undergone L2-5 fusion 27 years ago, presented with persistent lower back pain and gait dysfunction with imaging findings of L5/S1 spondylosis and ASD. Under intraoperative computed tomography navigation, left L5/S1 ATP interbody fusion was performed with simultaneous L5/S1 percutaneous facet screw fixation.

Results: The abdominal incision was 4.0 cm and the single posterior incision was 1.5 cm long. Blood loss was lower than 10 mL, and the procedure lasted for less than 1.5 hours. The patient was discharged to rehabilitation after 3 days.

Conclusion: ATP interbody fusion enabled the placement of an interbody device with a large footprint to promote fusion and reduce the risk of subsidence and pseudoarthrosis. The combined use of interbody fusion and facet screws obviates the need to link to the previous construct.

Key Words: Anterior to psoas, Lumbar interbody fusion, Adjacent segment disease

INTRODUCTION

Lumbar spine fusion is efficacious in the treatment of a variety of conditions, including spinal instability, spondylolisthesis, and degenerative disease [1,2]. However, fusion of any spinal segments results in transmission of stress to unfused adjacent segments, the manifestation and sequelae of which are referred to as adjacent segment disease (ASD) [3]. ASD occurs in 9% of patients after long-segment lumbar fusion [4]. The most common surgical method to treat ASD is to extend the prior fusion across the affected levels [5,6]. Approaching this through a revision of posterior instrumentation has many disadvantages, including the need to expose all or part of the previous hardware construct, extensive paraspinal muscle dissection, challenges in identifying normal anatomy in the setting of prior laminectomy which translates to greater operative time, more postopera-

tive pain, slower postoperative recovery and return to function, all of which lead to a higher risk of postoperative complications and result in greater utilization of healthcare resources. Minimally invasive (MIS) options to treat ASD have a significant advantage in this regard. The "standalone" lateral lumbar interbody fusion and anterior lumbar interbody fusion (ALIF) use an interbody with a large footprint to promote fusion across the disc space, without needing a posterior exposure. However, these approaches have anatomical limitations. ALIFs are typically limited to the L4–5 and L5–S1 disc spaces by the iliac bifurcation, and a high sacral slope can make access to the L5–S1 disc space difficult. Lateral interbody fusions are limited to the midlumbar region by the rib cage superiority and the iliac crest inferiorly [7,8]. In contrast, the anterior-to-psoas (ATP) interbody fusion allows access to nearly the entire lumbar spine, all with a small incision and large interbody footprint. Here we present the case of an 80-year-old male who underwent ATP interbody fusion with facet screw instrumentation for symptomatic L5–S1 ASD after long-segment lumbar fusion.

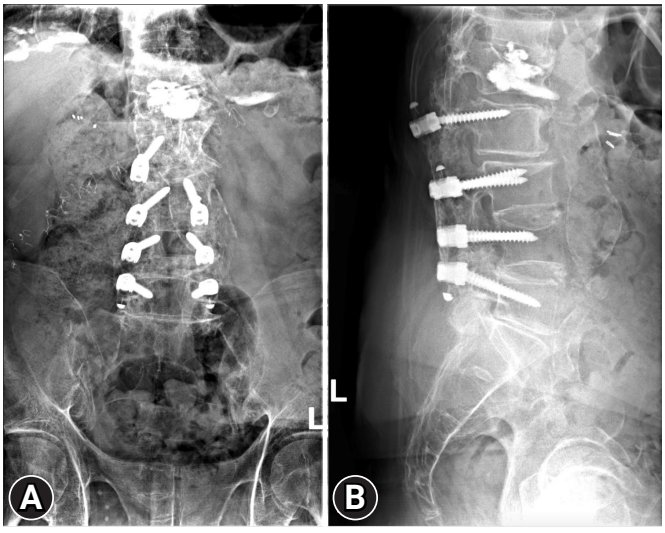

Figure 1. Preoperative x-ray showing prior L2–5 fusion with L1 intravertebral cement anteroposterior (A) and lateral views (B) in an 80-year-old male patient with L5–S1 spondylolysis and symptomatic adjacent segment disease.

MATERIALS AND METHODS

An 80-year-old male presented to our clinic for persistent lower back pain causing gait and mobility difficulty. He had a complex past medical history including chronic obstructive pulmonary disease, abdominal aortic aneurysm, prostate cancer, hypothyroidism, and osteoporosis. Twenty-seven years prior to presentation, he underwent an L2–5 laminectomy and fusion and required subsequent revision for a broken screw. Ten years prior to presentation, he had an L1 compression fracture requiring L1 intravertebral cement augmentation. Preoperative x-rays demonstrated L5–S1 ASD and spondylosis (Figure 1).

IRB approval and patient consent was obtained for the study.

RESULTS

1. Intraoperative Course

The patient, after consenting to the procedure, was positioned in the lateral decubitus position with the left side up. A left-sided exposure is favored for the ATP approach due to the relative ease of mobilizing the aorta compared to the inferior vena cava (IVC). A standard flat surgical table was used, and the patient was taped just below the axilla, below the iliac crest, and across the knees. The operative field was prepped with chlorhexidine scrub from the level of approximately T8 down to the level of the iliac crest, from the anterior abdomen at the umbilicus lateral to past midline along the back. An intraoperative computed tomography (CT) scan was obtained for navigation with placement of the navigation array in the left iliac crest. A 4-cm incision was made anterior to the iliac crest in the lateral abdomen. Each subsequent abdominal muscle layer was opened respecting the fiber orientation of the external oblique, internal oblique, and transversalis muscle, until retroperitoneal fat was reached. The retroperitoneal fat was mobilized anteriorly with endoscopic Kittners until the psoas muscle was visualized and the left common iliac artery was seen pulsating. Careful dissection was performed medial to the common iliac artery down to the promontory of S1. A table-mounted ATP retractor system from Pantheon Surgical (Georgetown, TX, USA) consisting of 4 blades to retract retroperitoneal contents was introduced and secured into place at the L5–S1 space. Fluoroscopy was then brought in to confirm the L5–S1 level (Figure 2). The discectomy was then performed with gentle distraction across the disc space using a combination of the Cobb, rasp, and pituitary to remove all disc material from the disc space. The adequacy of disc preparation was confirmed through both direct visual inspection and tactile feedback of instruments. A static interbody device measuring 40x18x12 mm with 8° of lordosis was introduced into the disc space with a pivoting action. Fluoroscopic imaging was used to confirm adequate disc preparation and interbody device placement (Figure 2). For the percutaneous L5–S1 facet screws, navigation was used to determine the location of the ideal skin incision and trajectory to navigate across the L5–S1 facet. A single 1.5-cm incision was

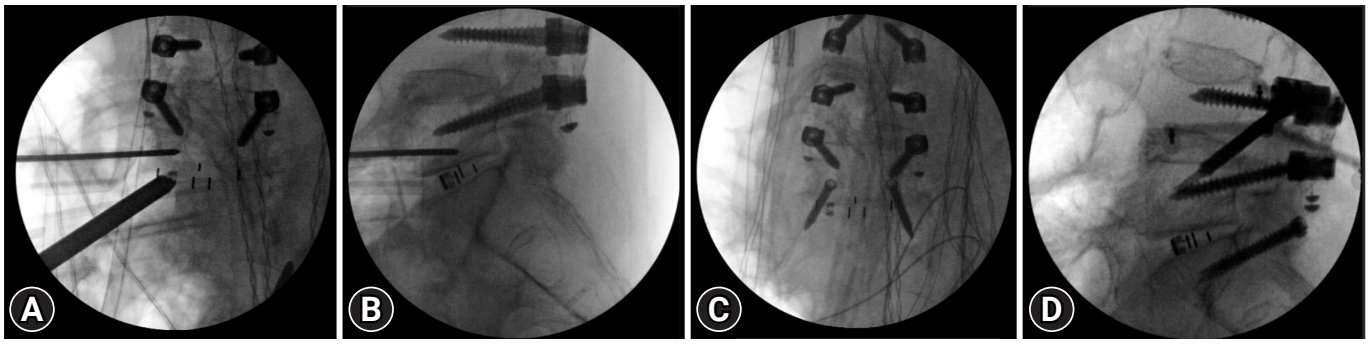

Figure 2. Intraoperative fluoroscopy demonstrating the interbody device being inserted using an O-arm navigation system in anteroposterior (A) and lateral views (B) and final images showing appropriate facet screw placement in anteroposterior (C) and lateral views (D).

made at midline through which both screws could be introduced in the appropriate trajectory. The monopolar cautery was used to dissect through the subcutaneous fat, fascia, and superficial muscle along each screw trajectory to access the starting point of the facet screws. With patient remaining in lateral position, each Trans-Facet Screw was placed under navigation, with starting point at medial edge of inferior articulating process of L5 and orientation through the facet joint towards the pedicle of S1 (Medtronic, Dublin, Ireland). The entire procedure lasted less than 1.5 hours with minimal blood loss.

2. Postoperative Course

Postoperatively, the patient reported minimal back and abdominal pain and used IV narcotics for only a few hours after surgery. On neurological exam, he had full strength in all muscle groups of the lower extremities. He was discharged to inpatient rehabilitation after 3 days for self-care retraining, adaptive equipment training, endurance, strength, home exercise program, functional mobility and transfer as related to activities of daily living. His functional independence measure scores greatly improved from admission to discharge (Table 1). He returned to clinic at 2 weeks postoperatively and continued to do well with improving back pain and no new neurological symptoms. Ten-week postoperative CTs showing facet screw placement and signs of early bony fusion across the facet joint (Figure 3).

Table 1. Functional independence measurement (FIM) scores at admission and discharge

FIM scores	Admission	Discharge
Eating	7	7
Grooming	5	6
Bathing	2	5
Dressing-upper body	2	6
Dressing-lower body	2	5
Toilet transfer	4	6
Toileting	1	6
Tub/shower transfer	1	6

1, total assistance needed; 7, complete independence.

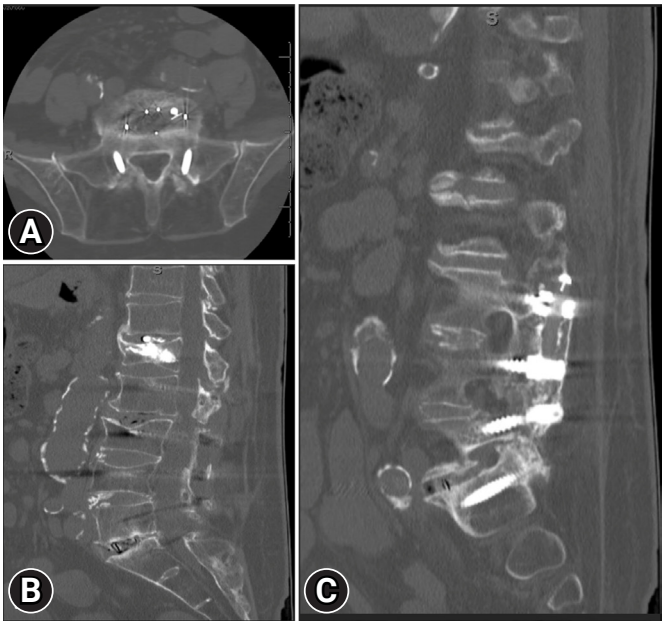

Figure 3. Ten-week postoperative computed tomography scans showing S1 pedicle screw placement in the axial (A) and sagittal views (B), as well as signs (C) of early bony fusion across the facet joint.

DISCUSSION

The ATP approach was first described in 1997 by Mayer et al. to gain access to a wider corridor in the lumbar spine and avoid some of the complications that can occur with anterior and lateral lumbar interbody fusion [9,10]. Docking onto the spine

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anterior to the psoas, instead of on the psoas, decreases rate of lumbar plexus injuries and avoids postoperative psoas pain. Further, the access corridor anterior to the psoas means neuromonitoring can usually be avoided. However, care must be taken to avoid the ureter during the approach and to prevent traction and avulsion of the iliac vessels. An approach from the left side is favored due to the presence of the aorta on the left side and the IVC on the right side. Moreover, at L5–S1, a left-sided approach may be complicated by a prominent Ilio-lumbar vein 95% of the time on the left. A decision can be made to go inside the bifurcation, lateral to the vessels, or between common iliac artery and vein. This case report is the first to describe a method of combining ATP interbody fusion with facet fixation to obtain both anterior and posterior support in treating ASD. Additionally, it highlights the unique utilization of a single incision for placement of transfacet screws, which facilitates a viable, MIS option for surgeons to perform posterior augmentation in select patients with prior long segment fusion.

A pooled meta-analysis of 503 patients comparing those who underwent a MIS transforaminal lumbar interbody fusion (TLIF) with those who underwent the ATP interbody fusion technique for the treatment of lumbar degenerative diseases revealed significantly lower subsidence levels, increased disc height, and greater foraminal cross-sectional area in the latter group [11]. There are several potential reasons for this difference. First, the ATP approach allows for placement of an interbody device with a larger cross-sectional footprint, allowing for more uniform disc height restoration across the width of the vertebral body. Second, the use of this interbody with a larger footprint more evenly distributes pressure across the adjacent end plates, decreasing risk of subsidence. A larger annulotomy can be created along the anterolateral aspect of the disc space, allowing for greater endplate cleaning.

The ATP approach to interbody fusion is a relatively newer approach compared to the TLIF and lateral interbody fusion. Utilizing the former method in combination with transfacet screws avoids the need to expose previous instrumentation or revise the long construct in order to extend the fusion to L5–S1. Some studies have reported a greater rate of interbody migration in ATP interbody fusion compared to lateral interbody fusion, although fusion rates and rate of overall complications were the same between the 2 groups [12,13]. Given that the majority of studies to this point are retrospective cohort analyses, the long-term outcomes after ATP interbody fusion still need to be analyzed.

CONCLUSION

ATP interbody fusion facilitates the placement of an interbody device with a large footprint for fusion and minimizes the risk for subsidence and pseudoarthrosis. Its combined use with percutaneous L5–S1 facet screws allows for both anterior and posterior instrumentation. This method obviates the need to expose and connect to the prior fusion construct.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Less Invasive Triangular Osteosynthesis in the Management of AO Type-B Unstable Sacral Fractures

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Objective: This prospective cohort study investigated the clinical and radiological efficacy of triangular osteosynthesis (TO) in the management of AO type-B unstable sacral fractures.

Methods: All patients with unstable AO type-B sacral fractures were included in this study. They were evaluated clinically and radiologically and underwent TO. Pre- and postoperative clinical parameters included the visual analogue score (VAS) for back pain, Oswestry Disability Index (ODI), and Gibbon classification. Radiological parameters included x-rays and multislice 3-dimensional computed tomography scans of the pelvis and the Tornetta and Matta criteria for fracture reduction.

Results: This study included 30 patients (17 males and 13 females; mean age, 31.63±9.65 years). The reported causes of trauma were a fall from height in 17 patients, road traffic accident in 11 patients, and hard objects falling onto the pelvis in 2 patients. According to the AO spine sacral fracture classification system, 8 cases were type B2 and 22 were type B3. At the last postoperative follow-up, the mean VAS improved from 7.77±1.19 preoperatively to 3.97±1.59 ($p<0.001$), the mean ODI was 15.27±3.34, and the Gibbon classification of cauda equina injury improved from 2.87±0.97 preoperatively to 1.27±0.52 ($p<0.001$). According to Tornetta and Matta criteria for fracture reduction, the results were excellent (<4 mm) in 73.3% of patients, good (4–10 mm) in 20%, and fair (10–20 mm) in 6.7%. All patients experienced complete fracture healing.

Conclusion: TO is a less invasive, safe, and effective option for the management of unstable AO type-B sacral fractures with good clinical and radiological outcomes.

Key Words: Triangular osteosynthesis, Sacral fractures, Spino-pelvic fixation

INTRODUCTION

Biomechanically, the sacrum carries weights from the spine to the pelvis representing a suspensory bridge between iliac bones. It forms the posterior aspect of the pelvic ring and has therefore been described as the keystone of the pelvic ring [1].

Sacral fractures mostly occur because of high-power blunt trauma such as road traffic accidents (RTAs) or fall from height (FFH). Most of these fractures are disastrous injuries that may be associated with a high incidence of other injuries. These multiple systems injuries lead to serious morbidity and mortalit. [2,3].

The important aspects that must be evaluated while tailoring a treatment strategy are the fracture etiology, correct anatomical evaluation of the fracture, neurological condition, soft tissue status, stability, and trauma affecting other systems [4].

Sacral fractures can be treated either with conservative treatment or surgery [5]. Operative management that speeds the recovery progress and decreases the incidence of bed-ridden complications has been recommended for unstable fractures [6].

The goals of operative management are to accomplish reduction and fixation, achieve union in adequate position, restore the biomechanical stability, avoid deformity, and start rehabilitation as early as possible to achieve early return to activity [7,8]. Multiple modalities of internal fixation are available for the management of sacral fractures such as transiliac rods, iliosacral screw fixation, lumbopelvic fixation, and triangular osteosynthesis (TO) [9,10].

TO includes a combination of a vertical fixation between the lower lumbar spine and the posterior ilium on one hand, and a horizontal fixation with an iliosacral screw on the other hand. Therefore, it grants reconstruction of multiplanar stability incorporating the horizontal and vertical planes of the lumbosacral junction [11]. Compared to similar techniques, it is considered a minimally invasive technique with comparable biomechanical properties [9].

This technique has a low incidence of wound infection and soft tissue destruction compared to other techniques [11]. Cadaveric and biomechanical evaluation have shown that TO has the most biomechanically stable construct compared to other modalities of internal fixation of the sacrum [8].

This study aims to evaluate the clinical and radiological outcome of TO as a less invasive fixation technique in the management of traumatic AO type-B unstable sacral fractures.

MATERIALS AND METHODS

This prospectively designed study included patients presented to Suez Canal University Hospital Emergency Department between January 2020 to December 2021 with unilateral AO sacral fracture classification type-B [12] with minimum 12-month follow-up. Exclusion criteria were, unstable iliac fractures, first sacral vertebra comminuted fracture, fractures at iliac entry site for iliosacral screw, major psychiatric illness, pregnancy, general contraindication for surgery, pathological fractures (e.g., osteoporosis and tumors), lumbosacral transitional vertebrae.

All patients were submitted to medical history taking including, demographic data (age and sex) and mechanism of trauma. In addition, full clinical assessment was done including general examination (vital signs, complete trauma survey, and assessment of any associated soft tissue injuries), neurological assessment of lower limbs (motor, sensory, sphincters, and reflexes assessment). Back pain was assessed by visual analogue score (VAS), cauda equina injury was assessed by Gibbon classification with its 4 subtypes; type 1: none, type 2: paresthesia only, type 3: lower limb motor deficit, type 4: bowel/ bladder dysfunction [13]. Also, radiological assessment included x-ray lumbosacral spine (anteroposterior [AP] and lateral views). X-ray pelvis (AP, lateral, inlet, and outlet views) and multislice 3-dimensional computed tomography (CT) scan lumbosacral spine and pelvis for typing of the sacral fracture, measurement of vertical displacement according to Tornetta and Matta [14] and identifying the anterior pelvic ring injury.

The study was approved by the Institutional Review Board of Suez Canal University Hospital (IRB No. 4270#). All patients formally consented before being scheduled for surgery. We followed the World Medical Association Declaration of Helsinki-Ethical Principles for Medical Research Involving Human Subjects throughout this study.

1. Surgical Technique

All patients underwent TO using unilateral open lumbo-iliac fixation and percutaneous iliosacral screw fixation, the lumbar anchoring point was L5 transpedicular screws in all patients. No patients underwent surgical decompression during the procedures. One case of associated L1 fracture underwent isolated short segment transpedicular fixation (T12-L1-L2) in addition to TO.

Surgery was scheduled as soon as the vital parameters and organ function of the patient were stable to achieve optimal preparation of the patient and improve surgical environment. The procedure was conducted under general anesthesia with patients in prone position on radiolucent operating table. All surgeries were performed by the same operative team.

In case of fracture displacement, fracture reduction was corrected by longitudinal traction done by an assistant and in case of rotation of the pelvis, was corrected with a pin inserted in the posterior iliac bone to correct mal rotation of the injured hemipelvis.

In case of anterior pelvic ring injury such as pubic ramus fracture, no direct fixation was applied, only the posterior fixation was enough.

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2. Percutaneous Iliosacral Screw Fixation

Skin marking for the lateral iliosacral screw was done by drawing 2 perpendicular lines: a horizontal line at the level of greater trochanter and a vertical line at the level of anterior superior iliac spine. The entry point was 2 cm above and caudal to the point of intersection and 1-cm skin incision was made. On the lateral sacral fluoroscopic view, the entry point was in the middle of the body of the first sacral vertebra just below the iliac cortical density line. A cannulated guide was advanced into the ilium. On the lateral view, the tip of the K-wire was placed on the ideal starting spot and impacted into place with a hammer to prevent slipping. Both pelvis inlet and outlet images were obtained. After advancing the K-wire and checking its position in all views a measure was introduced over to measure the depth for proper screw length. A power drill was introduced over the wire then appropriate length cannulated screw was advanced over the guidewire under fluoroscopy. An obturator view was obtainedto ensure adequate screw impaction over iliac bone. Closure of the incision with single skin suture.

3. Open Lumbo-Iliac Fixation

Under general anesthesia and guided by operative fluoroscopy, a small (7 cm) lumbosacral ipsilateral paramedian skin incision was done. The fascia was opened paramedially, and transmuscular dissection was done to reach L5 pedicle screw entry point lateral to the superior articulation facet of L4–5 facet joint. An appropriate size poly-axial L5 pedicle screw was inserted under fluoroscopy guidance. The iliac screw entry point is dissected over the postero-medial aspect of the posterior superior iliac spine (PSIS). The inferomedial part of the PSIS was excised to create a room for the head of the screw to avoid screw prominence through the skin especially during setting.

A screw channel was cannulated in a lateral downwards tilted direction towards the ipsilateral greater trochanter between the inner and outer table of the ilium followed by placement of the iliac screw under fluoroscopy guidance above the greater sciatic notch. A connecting rod of appropriate length and proper bend was applied between L5 pedicle screw and iliac screw. L5 pedicle screws used were 6.5 mm in diameter and 45 mm in length in all cases, iliac screws were 7.5 mm in diameter with length ranged from 75 to 85 mm. Iliosacral screws were cannulated 7.3-mm screws with length ranged from 80 to 100 mm. Copious saline irrigation was done followed by wound closure in layers with closed suction drain (Figures 1–3).

4. Postoperative Management

Operative details were recorded including length of back incision, operative time, operative blood loss, operative complications, and hospital stay.

Postoperative medications include 48 hours of intravenous (IV) 3rd generation cephalosporine antibiotics and IV analgesics. Immediate postoperative full neurological assessment for any added deficit was done. Patients started ambulation on the first postoperative day (if not contraindicated due to other injuries). Patients were allowed to bear weight and sit as tolerated.

5. Follow-up

According to follow-up protocol, patients were followed at 3 months postoperative then at 3 months interval for at least 12 months after surgery. At each visit the following parameters were reported: clinical parameters included VAS for back pain, neurological examination, Gibbon classification of cauda equina injury and Oswestry Disability Index (ODI). Radiological parameters included: x-ray lumbosacral spine: AP and lateral views, x-ray pelvis: AP, lateral, inlet, and outlet views. Multislice 3-dimensional CT scan lumbosacral spine and pelvis were performed at 6-month follow-up and if there would have been an event that requires rescanning. Fracture healing was evaluated by presence of connecting bony trabeculae and callus formation. Presence of radiolucency or loss of reduction is suggestive of loosening and implant failure.

RESULTS

Out of 36 patients recruited for this study, a total of 30 patients who completed a minimum of 12-month follow-up were reported. According to AO Spine sacral fractures classification system, 22 patients were type B3 and 8 patients were type B2. Anterior pelvic ring injury, pubic rami fractures were reported in 19 patients (63.3%). Table 1 summarizes patients' data. Preoperative neurological assessment revealed that 12 patients (40%) were intact, 18 (60%) have sensory deficit in lower limbs, 12 (40%) have motor deficits in lower limbs, and 10 (33.3%) have saddle area hypesthesia/anesthesia. According to Gibbon classification of cauda equine injury, 12 patients were Gibbson I, 6 were Gibbson II, 2 were Gibbson III, and 10 were Gibbson IV (Table 1).

The reported associated injuries included: retroperitoneal hematoma in 5 patients (16.7%), intraperitoneal abdominal collection in 3 patients (10%), other spine injures including

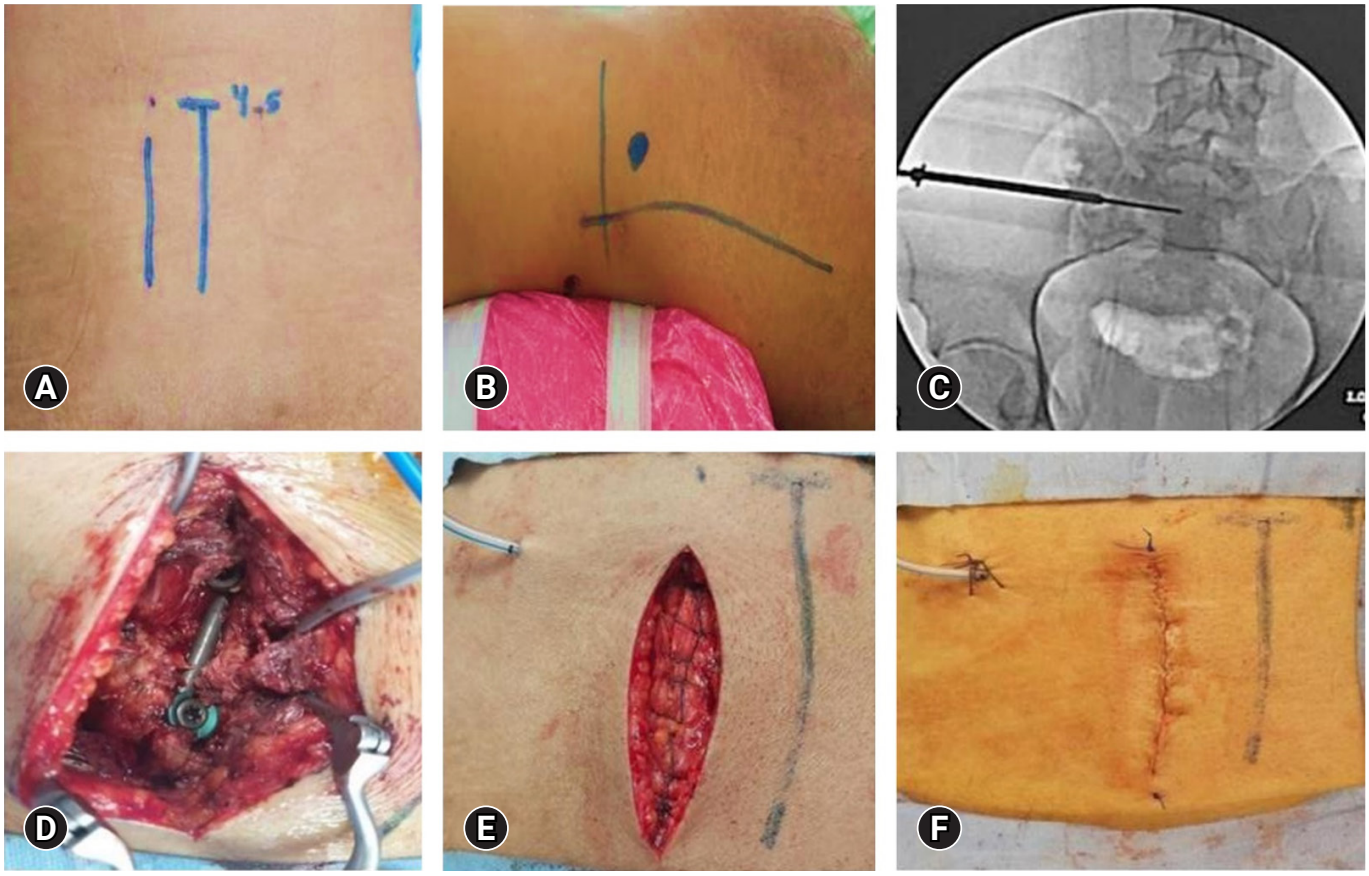

Figure 1. Operative images of a 30-year-old male patient who presented after a hard object fell onto the pelvis (Gibbons type I and AO type B3-N0-M3). (A) Identification of the midline and paramedian skin incision. (B) Skin marking for the iliosacral screw by drawing 2 perpendicular lines (a horizontal line at the level of the greater trochanter and a vertical line at the level of anterior superior iliac spine). The entry point was 2 cm above and caudal to the point of intersection. (C) Fluoroscopy image pelvic inlet view showing iliosacral screw insertion over K-wire and (D) the L5 screw and iliac screw connected by the rod. (E) Closure of the lumbosacral fascia with a continuous absorbable suture. (F) Skin closure with a continuous subcuticular absorbable suture.

T 12 fracture, L 1 fracture and lumbar transverse processes fractures in 2 patients (6.7%), lower limb fractures in 5 patients (16.7%), pneumothorax in 4 patients (13.3%), bladder injury in 3 patients (10.0%), vaginal injury in 2 patients (6.7%), and head injury in form of skull fissure and intra cranial hemorrhage in 2 patients (6.7%) (Table 2).

The meantime till surgery was 5.87±2.45 days (range, 3–14 days). The mean length of the skin incision was 7.1±0.99 cm (range, 6–9 cm). The mean operative time was 114.0±37.01 minutes (90–270 minutes), the mean operative blood loss was 221.67±103.9 mL (range, 100–500 mL). the mean hospital stays was 8.4±2.76 days (range, 5–18 days), the mean follow-up period was 15.1±2.29 months (range, 12–19 months) (Table 1).

1. Radiological Outcome Assessment

All our cases demonstrated fracture healing and bony union. No implant breakage or backing-out were reported over the follow-up period. No radiolucency around implant was detected. According to Tornetta and Matta criteria for fracture reduction, the preoperative fracture displacement was <4 mm in 5 cases (16.7%), 4–10 mm in 10 cases (33.3%), 10–20 mm in 8 cases (26.7%), and > 20 mm in 7 cases (23.3%). Postoperatively, the results were excellent (<4 mm) in 22 cases (73.3%), good (4–10 mm) in 6 cases (20.0%), and fair (10–20 mm) in 2 cases (6.7%).

2. Functional Outcome Assessment

At the last postoperative follow-up, the mean VAS improved from 7.77±1.19 (range, 6–10) preoperatively to 3.97±1.59 (range, 1–7) ($p<0.001$), the mean ODI was 15.27±3.34 (range, 12–24), and the Gibbon classification of cauda equina injury improved from 2.87±0.97 (range, 1–4) preoperatively to 1.27±0.52 (range, 1–3) ($p<0.001$) (Table 3).

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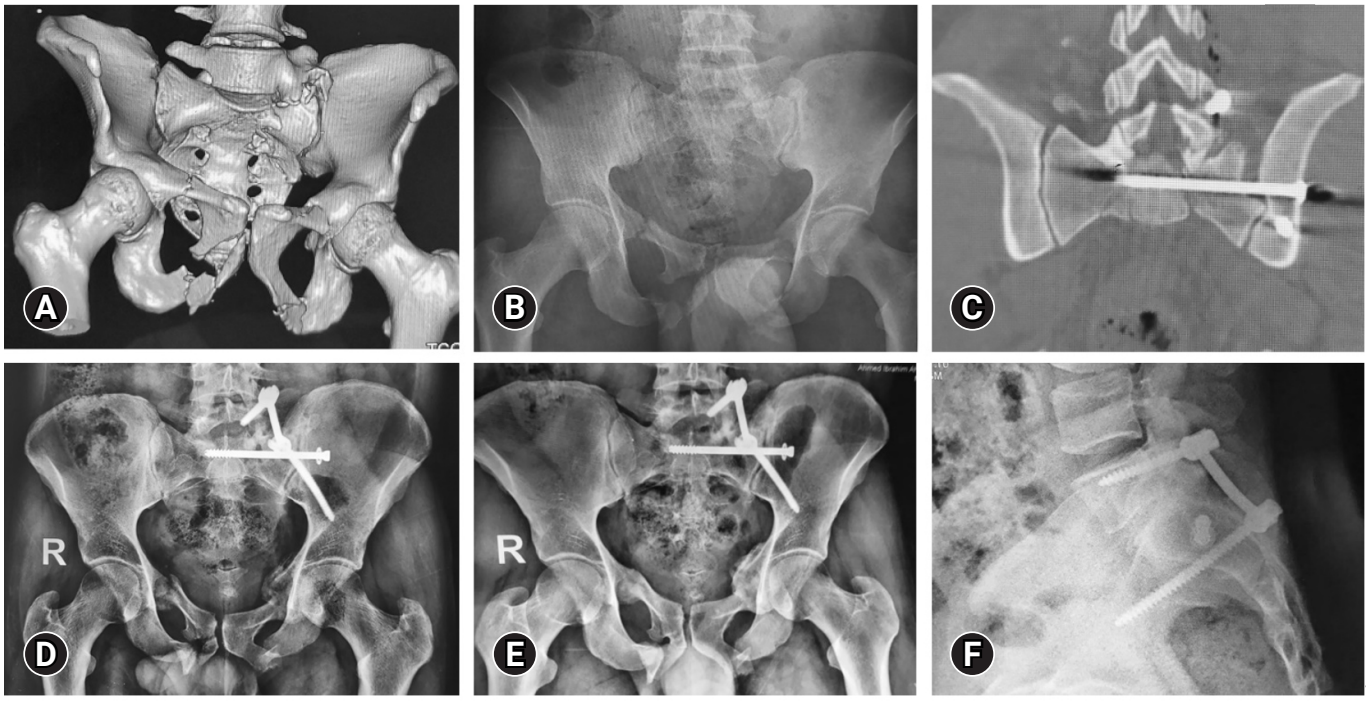

Figure 2. Images of the same patient as in Figure 1. (A) Three-dimensional multislice computed tomography (MSCT) scan. (B) Anteroposterior (AP) plain radiograph showing left-side AO type B3-N0-M3 sacral fracture, and associated bilateral superior and inferior pubic rami fractures. (C) Coronally reformatted MSCT scan showing the iliosacral screw in position. (D, E) AP plain radiographs showing adequate alignment and bone healing at 3 and 12 months respectively. (F) A lateral radiograph showing an adequate construct at 12 months.

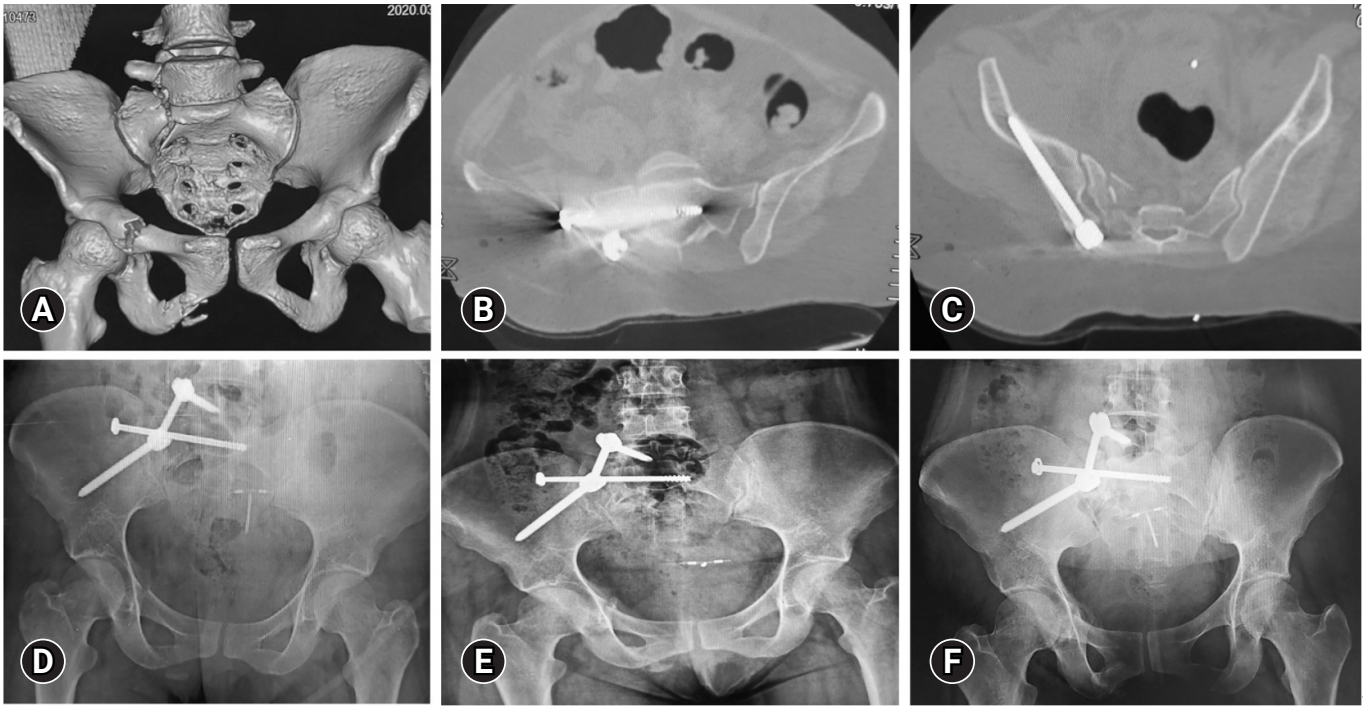

Figure 3. Images of a 33-year-old female patient who presented after a fall from a height, Gibbus I. (A) Three-dimensional multislice computed tomography (MSCT) scan showing right side, AO type B3-N0-M3 sacral fracture, with the following associated injuries: T12 fracture, L5 transverse process fracture, and superior and inferior right pubic rami fractures. (B) Axial MSCT image showing the iliosacral screw in position. (C) Axial MSCT image showing the right iliac screw in position. (D–F) Anteroposterior plain radiograph showing adequate alignment and bone healing at 3, 6, and 12 months respectively.

Reported complications were 1 patient developed pelvic retroperitoneal hematoma postoperative that was not present on preoperative pelvi-abdominal CT scans, mostly due to misdirected K-wire breaching the anterior border of the sacrum and mostly injuring the presacral venous plexus. The condition was diagnosed immediately postoperative as the patient developed hypovolemic shock. Maximum hematoma diameters were (10 cm, 8 cm, 6 cm). Patient was managed conservatively with multiple follow-up pelvi-abdominal ultrasound and CT scan and keeping the patient vitally stable using IV fluids and blood transfusion. Patient was discharged on day 6 postoperative.

Two patients had misdirected percutaneous iliosacral screw breaching the neural canal, which did not lead to added motor deficit and resulted in added sensory dysesthesia along S1 and S2 dermatomes. In 1 patient, the pain did not respond to medical treatment and the patient underwent another surgery to remove the iliosacral screw 3 months after surgery, and pain improved after. In the other patient, the pain was responsive to medical treatment and no revision surgery was needed. No other complications were recorded.

Table 1. Summary of the perioperative data of the study patients (n=30)

Parameter	Value
Age (yr)	31.63±9.65
Sex	
Male	17 (56.3)
Female	13 (43.7)
Type of trauma	
Fall from height	17 (56.7)
Road traffic accident	11 (36.7)
Fall of hard objects	2 (6.6)
AO fracture type	
B2	8 (26.7)
B3	22 (73.3)
Anterior pelvic ring injury	19 (63.3)
Gibson type	
Type I	12 (40.0)
Type II	6 (20.0)
Type III	2 (7.0)
Type IV	10 (33.3)
Operative time (min)	114.0±37.01 (90–270)
Operative blood loss (mL)	221.67±103.9 (100–500)
Hospital stay (day)	8.4±2.76 (5–18)
Follow-up period (mo)	15.1±2.29 (12–19)

Values are presented as mean±standard deviation (SD), number (%), or mean±SD (range).

Table 2. Reported associated injuries in study patients (n=30)

Variable	No. (%)
Retroperitoneal hematoma	5 (16.7)
Intraperitoneal abdominal collection	3 (10.0)
Thoracolumbar fractures	2 (6.7)
Lower limb fractures	5 (16.7)
Pneumothorax	4 (13.3)
Bladder injury	3 (10.0)
Vaginal injury	2 (6.7)
Head injury	2 (6.7)

DISCUSSION

Sacral fractures are one of the common and could be disabling clinical conditions with a major socioeconomic burden. Various therapeutic modalities could be offered to those patients. In this prospective cohort study, we reported a total of 30 patients were recruited for this study including 22 patients type B3 and 8 patients type B2 according to AO Spine sacral fractures classification system. All patients were managed with TO. The preoperative VAS and Gibbon classification of cauda equina injury improved from 7.77±1.19 to 3.97±1.59 and 2.87±0.97 to 1.27±0.52 respectively at the last follow-up.

The mean age in our study was 31.63 years which corresponds to similar studies reporting TO [4,11,15-17]. Other epidemiological studies [18,19] attributed this age incidence to reckless activities and concluded that trauma is a pathology of the young. Males represent 57% in our study which is close to the work of Schildhauer et al. [11], while in the study of Erkan et al. [4] males represent 37% of cases. This difference may reflect the socioeconomic background of patients reported.

All cases suffered high-energy trauma, which leads to multi-

Table 3. Pre- and postoperative clinical outcome parameters (n=30)

Parameter	Preoperative	Postoperative	Test of significance	p-value
VAS	7.77±1.19 (6–10)	3.97±1.59 (1–7)	F=301.490*	<0.001*
Gibbon type	2.87±0.97 (1–4)	1.27±0.52 (1–3)	Fr=47.0*	<0.001*
ODI	NA	15.27±3.34 (12–24)	NA	NA

Values are presented as mean±standard deviation (range).
VAS, visual analogue scale; ODI, Oswestry Disability Index; NA, not applicable; F, F test (analysis of variance); Fr, Friedman test.
*p≤0.05, statistically significant differences.

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ple organ injuries including neurological affection. The reported causes of trauma were FFH in 56.7%, RTA in 36.7%, and fall of hard objects on pelvis in 6.6% of cases, which was close to the work of Erkan et al. [4]. This figure was different from the study of Jindal et al. [15] conducted in India and reported that 82% of cases were due to RTA which could be explained by the fact that India has highest worldwide percentage of RTA deaths [20]. In our study, 59% of FFH where females and 82% of RTA were males. Epidemiological studies [19,21] reported that males were affected by trauma more than females and the most common injury among males was RTA while females were mostly victims of FFH. This data could explain variations in gender presentation and its relation to the mechanism of trauma.

Anterior pelvic ring and pubic rami fractures were reported in 63.3% in our study which corresponds to other studies [4,15,22], meanwhile reported associated injuries in our patients were diverse and close to other reports in the literature [4,15,22]. In the work of Schildhauer et al. [17] the most common associated injury was lower limb fractures. In a prospective study analyzing 100 patients with pelvic fractures, Lunsjo et al. [23] reported that the associated injuries (evaluated by the injury severity score) and not fracture stability were the most important predictors in defining mortality in these patients. The same results were found by Parreira et al. [24] in their study to evaluate the role of associated injuries on outcome of patients with pelvic fractures, which reported 103 patients. They concluded that the patient's outcome correlates with the severity of the associated injuries rather than the fracture pattern.

Twelve of our patients (40 %) had motor neurological deficit which was close to the work of other studies [2,11,16,17,25] who reported that 65%, 52%, 59%, and 57% of their patients had neurological deficit respectively. In our study, the mean pre- and postoperative Gibbon scores were 2.87 and 1.37 respectively with 52% improvement. This corresponds to the literature such as work of Hu et al. [16] with 3 and 1.8 mean pre- and postoperative Gibbon score respectively, and the work of Erkan et al. [4] with 2,7 and 1,3 mean pre- and postoperative Gibbon score respectively.

In our study, the mean period from trauma till surgery was 5.87 days (range, 3–14 days). A similar figure of 13 (range, 0–23), 9.7 (range, 3–21), 9 (range, 1–17), and 13 days (range, 0–28 days) days were reported by Schildhauer et al. [17], Jindal et al. [15], Mouhsine et al. [25], and Schildhauer et al. [11] respectively.

The postponement in the surgical intervention was attributable for optimization of the patients' homeostatic and physiological conditions and time taken for healing of any soft tissue injuries in the surgical field. According to a systematic review published in 2017 [26] that reported 30 articles and 309 patients to evaluate the effect of formal laminectomy and timing of surgery for patients with sacral fractures and neurologic deficit on clinical outcome, they reported no benefit of early surgery within 72 hours of trauma.

On the other hand, Routt et al. [27] in their series reported that surgery postponement more than 5 days were linked to weaker closed reduction percentage. Another series by Alaswad et al. [28] reported cases that were operated in the first 7 days had a higher percentage of wound healing problems compared to the cases that were operated later. This was attributed to the presence of soft tissue edema and less optimization of the general condition. They also reported no difference in sphincter and/or neurological injuries improvement whether the surgery was done early or late after trauma.

In this series, we did not have any cases of loss of reduction, implant breakage or nonunion which we attributed to multiple technical details in our surgical procedure. Fracture reduction was performed by applying longitudinal traction by an assistant and maintaining it till inserting iliosacral screw, which is applied first before lumbopelvic fixation. If the lumbopelvic fixation was applied at the beginning; this would prevent fracture compression and closure of fracture gap when the iliosacral screw was applied afterwards.

According to Tornetta and Matta criteria for fracture reduction, we reported excellent results in 73.3%, good results in 20% and fair results in 6.7% of patients. Hu et al. [16] reported excellent results in 72%, good results in 24% and fair results in 4% of patients.

Jindal et al.[15] reported fracture union and no loss of reduction in 21 out of 22 cases. Hu et al. [16] reported fracture union, no implant loosening or breakage in all 22 cases. Also, Mouhsine et al. [25] reported fracture union, no loss of reduction and no hardware loosening in all cases. In all the previous studies, iliosacral screw was applied at the beginning. On contrary, Sagi et al. [22] reported 8% percentage of nonunion which was attributed to the surgical technique that lumbopelvic fixation was applied before iliosacral screws which leads to inadequate compression of the fracture with the iliosacral screw.

Formal decompression and laminectomy even in the presence of neurological deficits is a controversial issue with multiple contradicting studies. We did not perform any decompression in this study as we considered that the neural injury is more related to the impact and shearing effect of trauma rather than neural compression. We relied mainly upon fracture reduction to help sacral alignment and improve neural injury recovery. Schmidek et al.[29] recommended early decompres-

sion in his study, which included 11 patients with transverse sacral fractures. Schildhauer et al. [30] reported better results for decompression and observed that 15 of 18 patients (83%) with a U-type sacral fracture with complete bowel and/or bladder dysfunction had some degree of neurological improvement after sacral laminectomy and lumbopelvic fixation. Erkan et al. [4] performed laminectomy on 5 patients in his study, which included 19 patients and reported superior neurologic outcomes. On the other hand, Sagi et al. [22] did not do laminectomy in his study with included 58 patients and reported good outcomes. Nork et al. [10] reported improvement in neurological status in 7 patients who underwent iliosacral screw fixation without laminectomy. Elhabashy et al. [7] also reported similar results on 20 patients with sacral fractures who underwent iliosacral screw fixation without laminectomy. Jindal et al. [15] did not perform laminectomy in his study and reported neurological improvements. In the work of Hu et al. [16], 13 patients underwent laminectomy with diverse outcomes that did not show any benefit of laminectomy. According to a systematic review published in 2017 [26], it does not have any benefit regarding improvement in neurological functions. This review also showed that neurological impairment is mainly because of crushing and shearing of the neural tissue rather than compression.

In this series, 1 patient had postoperative retroperitoneal hematoma and 2 had maldirected iliosacral screw with neural canal breaching. No one had wound infection or healing problems. This may be attributed to our less invasive technique as previously detailed, also adequate submergence of iliac screw head below the profile of posterior iliac crest by excising the inferomedial part of the PSIS to create a room for screw head which decreases screw prominence and leads to less tissue necrosis and less wound healing problems.

Schildhauer et al. [17] reported in 48 patients' series, 1 case of pulmonary embolism leading to death, 3 cases of tissue necrosis overlying iliac screw head requiring revision, and 3 cases of infection requiring implant removal. Jindal et al. [15] reported in 22 patients' series, 3 cases of wound infection with debridement in one and 2 patients of connecting rod back out. Hu et al. [16] reported 2 out of 22 patients with wound infection treated conservatively. Mouhsine et al. [25] reported a case of wound infection that needs implant removal of 7 patients. Erkan et al. [4] reported 26.3% wound infection rate that may be attributed to the midline skin incision with very large surgical field and excessive muscle dissection and devitalization. They also reported that wound healing problems increase in cases with degloving soft tissue injury.

Less invasive TO is a unique technique in a way that it combines both percutaneous fixation and mini-open minimally invasive techniques. In our study, iliosacral screw was inserted percutaneously and lumbopelvic system was applied unilaterally using paramedian skin incision and transmuscular dissection which leads to smaller surgical field, less tissue devitalization, less muscle injury, less operative time, and less blood loss. These technical advantages improve the clinical outcome and recovery, decrease wound infections and morbidities, and facilitates early rehabilitation and immediate weight bearing and early return to normal daily activities and work. The drawbacks and limitations of our described TO includes its indication in unilateral sacral fractures, and does not allow open fracture reduction.

We recommend that during TO, the iliosacral screw should be applied before lumbopelvic system to allow fracture reduction, attention must be paid to soft tissue injury and submergence of iliac screw head, and it can be performed for unstable sacral fractures in the presence of other injuries that prohibit early weight bearing as it allows safe mobilization during nursing care and decreases back pain.

Limitations of this study include a small sample size and representing a single spine center. Also reported data is not supported by biomechanical parameters and lacks a control group for comparison. However, being a prospective study with a homogenous group of patients treated with the same surgical technique and their classification according to the newly lunched and evaluated AO spine sacral trauma classification are strength points.

CONCLUSION

Our results suggest that TO is a safe and effective method in treatment of sacral fractures type-B AO Spine sacral fracture classification. It is a stable fixation construct that allows early weight bearing with good clinical and radiological outcomes and low complication rate through our 1-year follow-up period.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Accuracy and Clinical Outcomes of Fluoroscopy-Guided and Robotic-Assisted Percutaneous Pedicle Screw Fixation Performed by a Single Surgeon at a Single Center

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Objective: Fluoroscopy-guided percutaneous pedicle screw fixation (FGPSF) and its further development, robot-assisted percutaneous pedicle screw fixation (RAPSF), are minimally invasive spinal surgery (MISS) techniques. FGPSF is a standard technique at our hospital, and RAPSF incorporating artificial intelligence has been performed at our hospital since October 2021. This study compared these 2 techniques and analyzed their differences, accuracy, and clinical outcomes based on our experiences.

Methods: This study conducted a detailed analysis of screw accuracy and the clinical outcomes of 2 MISS techniques, FGPSF, and RAPSF. Screw accuracy was evaluated using the Gertzbein and Robbins scale, categorizing placements into grades A–E, with grades A and B considered clinically acceptable. Accuracy was assessed using postoperative computed tomography images for FGPSF and intraoperative O-arm scan images for RAPSF. Clinical outcomes were compared by examining parameters, such as hospitalization duration, C-reactive protein (CRP) normalization period, estimated blood loss (EBL), and preoperative/postoperative visual analogue scale (VAS) scores. Screw-related complications were reviewed. Independent image evaluations by nonparticipating spine specialists ensured objective and reliable assessments.

Results: Both FGPSF and RAPSF demonstrated high rates of clinically acceptable screw placement, with minimal breaches that required no repositioning. The clinically acceptable rates of FGPSF and RAPSF were similar (99.17% and 99.19%, respectively). Both groups also demonstrated similar clinical outcomes. The CRP normalization period, EBL, and ΔVAS (preoperative—postoperative) scores revealed no statistically significant differences between FGPSF and RAPSF. Neither group experienced screw-related complications; however, the RAPSF group exhibited a statistically significant shorter hospital stay than the FGPSF group.

Conclusion: This study compared the accuracy and clinical outcomes of FGPSF and RAPSF. Both methods demonstrated no significant differences in accuracy or clinical outcomes. Spine surgeons selected between the 2 methods based on individual patient needs, and additional research is required to fully understand the practical advantages of each technique in the clinical field.

Key Words: Robotic-assisted spine surgery, Minimally invasive surgical procedure, Pedicle screw, Accuracy

INTRODUCTION

South Korean society has become an aging society, and concomitantly, the number of patients suffering from degenerative spinal diseases, such as spinal stenosis and spondylolisthesis, has been steadily increasing [1]. Minimally invasive spine surgery (MISS) has been a safe and effective alternative to conventional open spinal surgery [2]. MISS enables spinal procedures with significantly reduced blood loss and soft tissue damage [3]. Fluoroscopy-guided percutaneous pedicle screw fixation (FGPSF) is one of these MISS techniques, whereas robot-assisted percutaneous pedicle screw fixation (RAPSF) is a more advanced form that incorporates artificial intelligence [4]. FGPSF is primarily used as the standard technique for posterior spinal fixation at our hospital. However, we have increasingly adopted the use of RAPSF since the initial application of percutaneous pedicle screw fixation using the CUVIS-spine robotic system (CUREXO, Seoul, Korea) in October 2021 [5]. Consequently, this study aims to compare and contrast these 2 minimally invasive screw insertion techniques, explore their differences, and analyze their respective accuracy and clinical outcomes based on our clinical experiences.

MATERIALS AND METHODS

1. Patient Selection

Two patient groups were investigated, including those who underwent oblique lumbar interbody fusion (OLIF) with FGPSF from April 2017 to December 2020 and those who received OLIF with RAPSF using the CUVIS-spine robotic system from October 2021 to November 2022. We followed the conventional approach that our hospital has been using for OLIF [6]. The screws inserted in both patient groups used Zenius (Medyssey, Jecheon, Korea) with a diameter of 6.0 or 6.5 mm. Both patient groups were evaluated for factors such as bone mineral density (BMD), body mass index (BMI), underlying disease, and medical history (Table 1). Clinical outcomes and radiological assessments were retrospectively analyzed, and relevant data were collected through our hospital's electronic medical records and the PACS (Picture Archiving and Communication System).

This study was approved by the Institutional Review Board (IRB) of Pusan National University Yangsan Hospital (IRB No. 55-2024-031).

Table 1. Demographic characteristics

Characteristic	FGPSF patients (n = 30)	RAPSF patients (n = 32)	p-value
Age (yr)	66.33 ± 6.54	66.16 ± 7.02	0.920
Sex, male:female	9:21	15:17	0.690
Body mass index (kg/m^2)	25.99 ± 3.29	26.01 ± 3.44	0.975
Bone mineral density	-0.10 ± 1.36	-0.07 ± 1.72	0.230
Diagnosed underlying disease			
Hypertension	15	19	0.705
Diabetes mellitus	7	10	0.760
Cardiovascular diseases	5	7	0.625
Smoking	2	5	0.310
Alcohol	16	17	0.590
Diagnosis			
HNP	15	14	0.462
Spinal stenosis	25	26	0.827
Spondylolisthesis	13	21	0.259
Scoliosis	6	5	1.000
Fusion level			
L3–4	2	1	
L4–5	25	30	
L5–S1	3	1	
Screw diameter (mm)			
L3			
6.0	0	0	
6.5	4	2	
L4			
6.0	0	2	
6.5	52	60	
L5			
6.0	0	1	
6.5	58	61	
S1			
6.0	0	0	
6.5	6	2	

Values are presented as mean±standard deviation or number.
FGPSF, fluoroscopy-guided percutaneous pedicle screw fixation; RAPSF, robotic-assisted percutaneous pedicle screw fixation; HNP, herniated nucleus pulposus.

2. Inclusion and Exclusion Criteria

The study included patients with persistent lower back pain and radicular pain that lasted for at least 3 months, as confirmed by preoperative magnetic resonance imaging. Participants were those who did not respond to medical treatment. This study excluded patients with pyogenic spondylitis, traumatic spinal disorder, or neoplasm. This study focused on patients operated on by a single surgeon who had passed a certain point in the learning curve at our hospital. Therefore, both patient groups under investigation underwent surgery by the same surgeon, and cases in which surgery was performed by different surgeons were excluded. Additionally, this study included patients who only underwent one level of OLIF while

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excluding those who underwent fusion surgery at ≥2 levels, as well as patients undergoing posterior decompressive laminectomy. Stringent inclusion and exclusion criteria were applied to maintain consistent evaluation, particularly in the context of screw fixation methods.

3. Screw Insertion Techniques

1) Procedure for FGPSF

Screw insertion is initiated by verifying a fluoroscopic true anteroposterior (AP) image at the targeted level (Figure 1). A skin incision was made at the lateral boundary of the discernible projected pedicle on the fluoroscopic image. A cannulated needle is placed into the central-lateral boundary of the projected pedicle after blunt dissection through the subcutaneous tissue, fascia, and muscles. Subsequently, the needle was advanced into the pedicle entrance on a fluoroscopic true lateral image (Figure 2). A K-wire is introduced through the cannulated needle to ensure that the cannulated needle does not extend beyond the medial pedicle border on the fluoroscopic true AP image. After removing the needle, the screw is inserted over the K-wire for precise screw fixation (Figure 3).

2) Procedure for RAPSF

The CUVIS-Spine robotic system, which was domestically designed, incorporates a main console, an optical camera, a floor-mounted robot arm, and a staff console (Figure 4). It uses intraoperative computed tomography (CT) scans for planning, initiated by an O-arm scan on the target vertebrae with a tracker fixed to the 2-level upper spinous process (Figure 5). To install the tracker, we check the level of spinous process 2 levels above the spinous process at the highest level of the screw fixation. And we dissect skin and muscle of the spinous process and then install the tracker. The subsequent steps involve planning and previewing (Figure 6), fixing the robot arm to the planned trajectory, and executing screw insertion into the target vertebrae. The system ensures precision through continuous checks, including skin and fascia release, working corridor creation, drilling, tapping, and trajectory validation with a ball tip probe, thereby improving control and accuracy in the surgi-

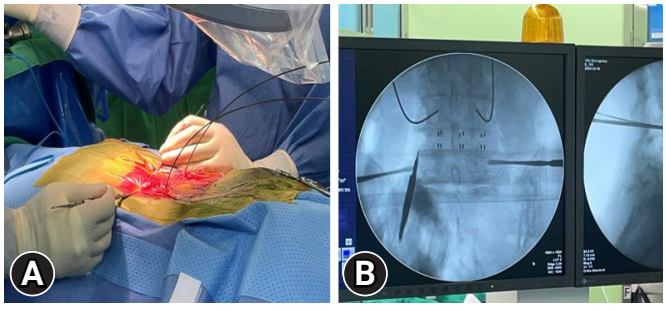

Figure 1. Verification of a fluoroscopic true anteroposterior image. (A) Confirm the location of the lateral border of the pedicle on the skin. (B) On a fluoroscopic true anteroposterior image, surgeon confirm the lateral border of the pedicle.

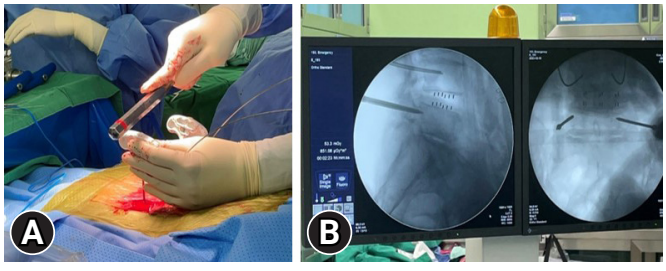

Figure 2. The cannulated needle is advanced into the pedicle entrance on a true lateral fluoroscopic image. (A) The cannulated needle is advanced into the skin. (B) On a true lateral fluoroscopic image, surgeon confirm that the tip of needle is placed at the pedicle entrance.

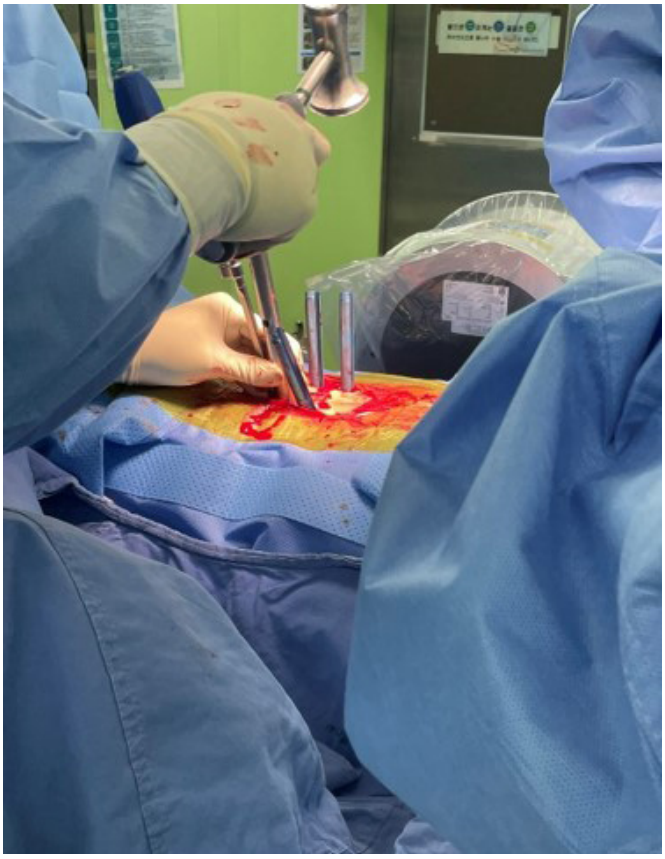

Figure 3. Percutaneous pedicle screw inserted under fluoroscopy guidance.

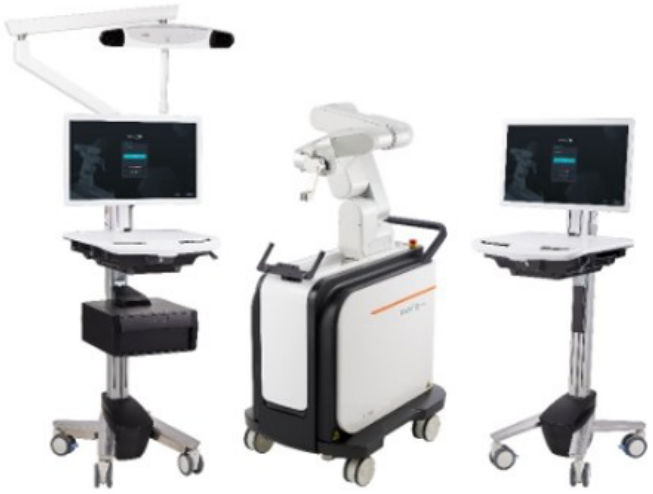

Figure 4. The CUVIS-Spine robotic system (CUREXO, Seoul, Korea). Available from: https://www.curexo.com/english/medical/sub05.php?kind=2.

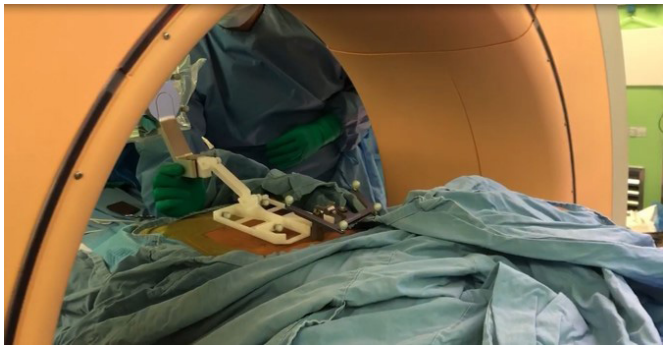

Figure 5. Intraoperative scan with the O-arm of the relevant screw insertion site.

Figure 6. Planning and previewing before screw insertion with a robotic system.

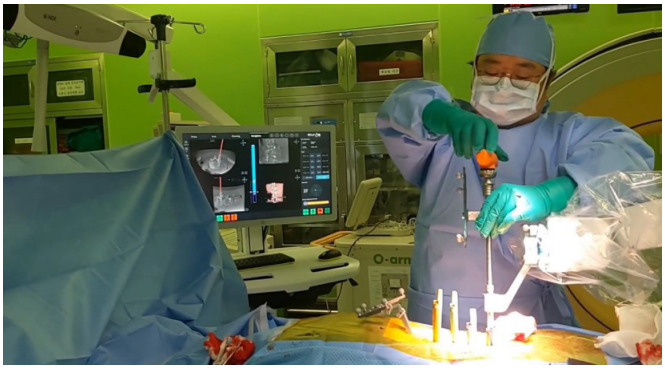

Figure 7. The actual process of robotic-assisted percutaneous pedicle screw fixation.

cal process (Figure 7).

4. Assessment of the Accuracy of Screw Placement

The Gertzbein and Robbins scale (GRS) was used to evaluate the accuracy of the inserted screws in each patient group [7,8]. The grading system for screw placement included grade A for screws placed within the pedicle, grade B for a cortical breach of the pedicle within 2 mm, grade C for a cortical breach of 2–4 mm, grade D for a cortical breach of 4–6 mm, and grade E for a cortical breach of >6 mm. Clinically acceptable grades were considered as A and B [9], and their rates in the 2 groups were investigated. The FGPSF group used postoperative follow-up CT images for screw accuracy evaluation. In contrast, the RAPSF group used intraoperative O-arm scan images conducted in the operating room immediately after screw insertion to assess screw accuracy. Two spine specialists, who were not involved in the surgery, performed image evaluations through duplicate verification.

5. Comparison of the Clinical Outcomes

The following parameters were investigated for each group to compare clinical outcomes: length of hospital day from the date of surgery to discharge, duration until postoperative C-reactive protein (CRP) normalization, amount of estimated blood loss (EBL), preoperative and postoperative (at discharge) visual analogue scale (VAS) score, and the occurrence of screw-related complications.

6. Statistical Analysis

IBM SPSS Statistics ver. 26.0 (IBM Co., Armonk, NY, USA) was used for analyses. Normally distributed continuous variables

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were presented as means with standard deviations, whereas categorical variables were expressed in quantity. Fisher exact test and chi-square test were used for categorical data analysis. Student t-test was utilized for comparing normally distributed independent data. A p-value of 0.05 indicated statistical significance.

RESULTS

This study included 30 and 32 patients in the FGPSF and RAPSF groups, respectively. The average age in the FGPSF group was 66.33±6.54 years, with a male: female ratio of 9:21, BMI of 25.99±3.29, kg/m^2, and BMD of -0.10±1.36. The average age in the RAPSF group was 66.16±7.02 years, with a male: female ratio of 15:17, BMI of 26.01±3.44 kg/m^2, and BMD of -0.07±1.72. A total of 120 screws were inserted using FGPSF, while 128 screws used RAPSF. RAPSF was successfully used to insert 124 screws, excluding 2 skiving screws and 2 failed screws. Skiving and failed screws, which were deemed risky, were converted to FGPSF and excluded from the analysis of clinically acceptable and breach occurrence rates.

1. Screw Accuracy

In the FGPSF group, 105, 14, and 1 screws were classified as grades A, B, and C, respectively, according to the GRS classification, with no screws graded as D or E. Further, 110, 14, and 1 screws in the RAPSF group were graded as A, B, C, and D, respectively, with no screws graded as E. In both groups, breaches in screws graded C or lower did not indicate a repositioning requirement; therefore, rescue fixation was not performed. The clinically acceptable rates in the FGPSF and RAPSF groups were 99.17% and 99.19%, respectively. Breach occurrence rates were 12.50% and 12.90% in the FGPSF and RAPSF groups, respectively (Table 2).

2. Clinical Outcomes

The clinical outcomes in both the FGPSF and RAPSF groups were as follows: CRP normalization period was 9.73±2.80 days and 7.94±5.14, EBL was 221.50±112.38 mL, and ΔVAS (preoperative—postoperative) were 4.10±1.32 and 3.78±0.97, respectively. No statistically significant differences were observed. Moreover, neither group experienced screw-related complications. Hospital days were 18.50±8.44 and 13.75±5.41 days in the FGPSF and RAPSF groups, respectively, revealing a statistically significant shorter hospital day for the RAPSF group (Table 3).

Table 2. Screw accuracy profile

Parameter	FGPSF (n = 120)	RAPSF (n = 128)
GRS		
A	105	110
B	14	13
C	1	2
D	0	1
E	0	0
Skiving screw	0	2
Failed screw	0	2
Clinically acceptable (GRS grade A or B) rate	119/120 (99.17)	123/124 (99.19)
Breach occurrence rate (GRS grade B, C, D, or E)	15/120 (12.50)	16/124 (12.90)

Values are presented as number or number (%).
FGPSF, fluoroscopy-guided percutaneous pedicle screw fixation; RAPSF, robotic-assisted percutaneous pedicle screw fixation; GRS, Gertzbein and Robbins classification system.

Table 3. Clinical outcomes

Parameter	FGPSF (n = 30)	RAPSF (n = 32)	p-value
CRP normalization period (day)	9.73 ± 2.80	7.94 ± 5.14	0.096
Hospital stay (day)	18.50 ± 8.44	13.75 ± 5.41	0.010*
Estimated blood loss (mL)	221.50 ± 112.38	182.81 ± 104.43	0.165
Screw-related complications	0	0	1.000
VAS score			
Preoperative	6.83 ± 0.75	6.78 ± 0.75	0.760
Postoperative	2.73 ± 0.98	3.00 ± 0.76	0.240
ΔVAS (preoperative—postoperative)	4.10 ± 1.32	3.78 ± 0.97	0.280

Values are presented as mean±standard deviation.
FGPSF, fluoroscopy-guided percutaneous pedicle screw fixation; RAPSF, robotic-assisted percutaneous pedicle screw fixation; CRP, C-reactive protein; VAS, visual analogue scale.
*p < 0.05, statistically signifcant differences.

DISCUSSION

Over the past few decades, spinal surgery has demonstrated remarkable advancements, introducing new technologies to improve surgical outcomes and enhance patient stability [10]. In general practice, FGPSF relied heavily on the surgeon's anatomical understanding and tactile feedback [11]. A new method called RAPSF has been introduced with the presentation of robotic technology. The adoption of RAPSF in spinal surgery represents a significant technological advancement in surgical accuracy and patient care [12,13]. The technological advancements mentioned are expected to reduce the risk of complications and maintain, on average, the clinical outcomes and accuracy of screws intraoperatively. The actual clinical effects and advantages of RAPSF compared with conventional screw fixation methods remain subjects of ongoing research

and debate despite their anticipated benefits [14,15]. Therefore, this study aimed to compare the results of FGPSF and RAPSF in spinal surgery. We compared the clinical outcomes, including screw accuracy, screw-related complications, length of hospital day, EBL, and CRP normalization period. We focused our efforts on obtaining an intuitive understanding of these 2 approaches, and we anticipate that the comparison results will offer insights into the optimal approach for spinal surgery. The accuracy of screw placement is crucial in spinal surgery, which directly affects surgical success and patient safety. The research results reveal no significant difference in accuracy between FGPSF and RAPSF. In a broader context, this study concludes that the accuracy of RAPSF is comparable to the reported accuracy of FGPSF [16,17]. The consistency of the results of this study with the accuracy results of previous analyzes of RAPSF conducted at our hospital indicates excellent reproducibility of the results [5]. This indicates that RAPSF may provide a more consistent accuracy level, thereby further supporting the notion that RAPSF can achieve a level of precision similar to that of FGPSF. Additionally, statistical significance was observed only in the length of hospital days in the RAPSF group, but the average values for CRP normalization period, EBL, and pre- and postoperative VAS were consistently lower in the RAPSF group. This indicates that RAPSF may demonstrate clear advantages over FGPSF in the context of MISS with continued research.

This study reveals that RAPSF represents a technologically advanced method compared with FGPSF, but RAPSF demonstrating clear superiority in terms of accuracy and clinical outcomes over FGPSF cannot be unequivocally stated. Furthermore, the challenges associated with robotic systems, technical complexity, and the cost of robotic equipment may present obstacles to the practical adoption of these technologies in a clinical setting [18,19]. However, continuous additional research is required to determine the practical benefits of these innovative technologies in a clinical environment, as robotic spine surgery systems still possess tremendous untapped potential for further development [20,21]. Effectively using robotic spinal surgery systems in the ever-evolving field of spine surgery requires the integration of such new technologies into clinical practice based on objective research data. This integration will be crucial for the future generation of spine surgeons. Moreover, spine surgeons would be provided with the option to select a surgical approach based on patient preferences and clinical considerations, in the light of the similarities in accuracy and clinical outcomes between the 2 screw fixation methods. In particular, the excellent reproducibility of RAPSF could be an appealing procedural option for young spinal surgeons with limited experience.

FGPSF posed challenges whereas RAPSF offered advantages based on our experience with specific cases and the previously reported advantages of RAPSF [12,13]. RAPSF demonstrated benefits in cases of poor radiation penetration due to excessive obesity, causing a less visible pedicle. Additionally, instances that involve patients with a stent from abdominal aortic aneurysm repair, where radiation interference from the stent affected precise pedicle visibility, and cases of revision screw fixation in patients who had previously undergone cement-augmented screw fixation, where the existing trajectory was accurately confirmed using the robot (Figure 8), emphasized the advantages of RAPSF.

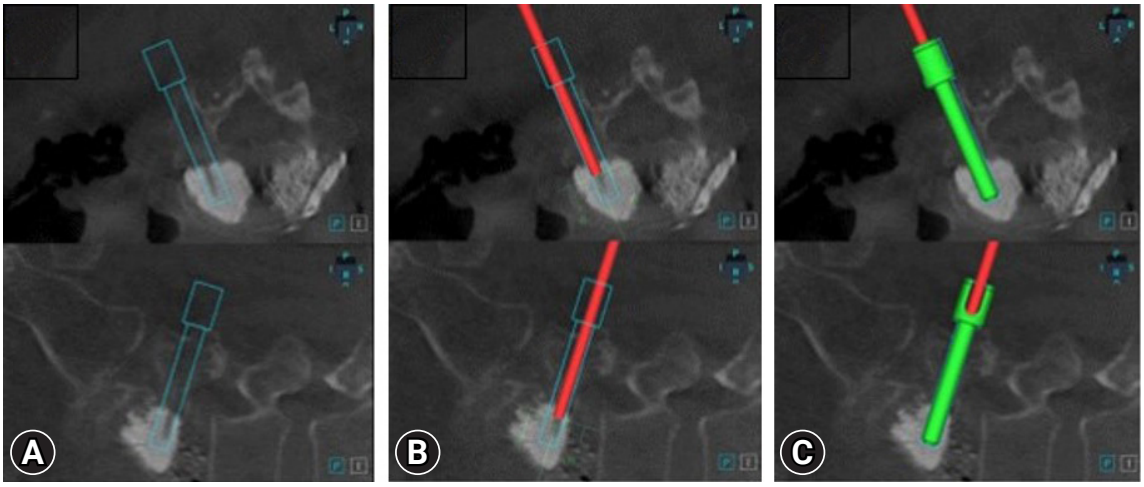

Figure 8. (A) Insertion of screws into the existing cement-filled trajectory planned using a robotic system. (B) Verifying that the existing trajectory matches ball tip probes (red rod) in the robotic system. (C) Accurately inserted screw along the planned path.

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This study has several clear limitations. First, the sample size of our study was small. Future studies should involve larger patient populations and randomized controlled trials to more accurately validate these results. Second, only patients who underwent 1-level OLIF were selected as control variables. However, additional research on multilevel fusion cases may be required for a more comprehensive analysis of the differences between FGPSF and RAPSF. Third, the follow-up period for the clinical outcomes of the patient group was short. Long-term follow-ups at 3 months, 6 months, and 1 year and beyond are essential to assess potential differences in clinical outcomes over time. Third this study did not included variables for the time on FGPSF and RAPSF and total radiation exposure. Finally, this study was conducted solely based on the results of research using the CUVIS-Spine robotic system. More convincing results were anticipated to be obtained if a systematic comparative analysis of various robotic systems is conducted.

CONCLUSION

RAPSF has been recently introduced as a contrast to conventional FGPSF, which relies to some extent on the surgeon's technical proficiency, with MISS advancement. This study compared RAPSF and FGPSF in terms of screw accuracy and clinical outcomes. The results reveal no significant difference in accuracy between RAPSF and FGPSF, with both techniques demonstrating high precision. RAPSF offers technological advancements, but it did not exhibit clear superiority in clinical outcomes compared with FGPSF. This study indicates that spinal surgeons can select between the 2 methods based on patient-specific requirements and clinical considerations. The reproducibility of RAPSF may be particularly advantageous for less experienced spinal surgeons, but further research is warranted to fully understand the benefits of RAPSF in the clinical field.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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Case Report

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Minimally Invasive Oblique Retroperitoneal Approach for Extraforaminal Lumbar Schwannoma: Technical Challenges and Literature Review

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Traditional surgical techniques for extradural lumbar schwannomas are associated with considerable morbidity, including spinal instability and injury to the viscera and lumbar plexus. Minimally invasive approaches decrease soft tissue damage, blood loss, and postoperative length of stay. For select extraforaminal schwannomas, a minimally invasive lateral transpsoas approach affords a direct surgical corridor. A 53-year-old obese female presented with 1 year of left iliopsoas weakness and L3 radiculopathy refractory to conservative management. Lumbar spine magnetic resonance imaging revealed a contrast-enhancing mass within the left psoas muscle consistent with an extraforaminal L3 schwannoma. The patient underwent minimally invasive oblique retroperitoneal surgical resection. Intraoperatively, the nerve root was splayed over the superior-lateral portion of the tumor limiting us to subtotal resection with nerve root preservation. The patient had improvement of pain and weakness that persisted at a 3-month follow-up. A minimally invasive lateral/oblique transpsoas approach provides a direct surgical approach for extraforaminal schwannoma. Patient body habitus and the nerve root relationship to the tumor may present limitations for the safe extent of resection.

Key Words: Lumbosacral plexus, Minimally invasive surgical procedures, Retroperitoneal, Schwannoma, Transpsoas

INTRODUCTION

Lumbar extradural schwannoma are uncommon, accounting for 2.4%–3.2% of all nerve sheath tumors [1,2]. Their rarity has prohibited methodologic examination in order to establish an optimal surgical approach for treatment [1]. Rather, the surgeon must consider the individual tumor's size, location, and involvement of adjacent structures when selecting a surgical approach. Traditional anterior open or laparoscopic retroperitoneal approaches require an access surgeon and extensive mobilization of the viscera. Posterior midline or paraspinal approaches have been employed with good results. However, these approaches involve disruption of muscular and ligamentous attachments, laminectomy, total or medial facetectomy, and possibly instrumented fusion for spinal instability [3].

Minimally invasive surgical (MIS) techniques have garnered increasing popularity in treating a variety of spinal pathologies due to their associations with less soft tissue disruption, decreased blood loss, and shorter hospitalizations [4]. More recently, Benjamin et al. [5] reported the use of a MIS lateral transpsoas approach for the successful resection of an extraforaminal L4 nerve root schwannoma. The lateral retroperitoneal transpsoas approach as described by Ozgur et al. [6] obviates the need for an access surgeon, and should present the most

direct approach to an extraforaminal lumbar nerve sheath tumor. In this report, we describe our experience with the use of a minimally invasive lateral transpsoas approach for resection of an extraforaminal L3 nerve root schwannoma. We provide a review of the literature on minimally invasive lateral surgical approaches to extraforaminal schwannomas and discuss technical challenges of consideration to the surgeon.

CASE REPORT

A 53-year-old obese (body mass index [BMI], 42.3 kg/m^2) female presented with over 1 year of progressive pain and numbness across the left anteromedial thigh. Physical examination revealed grade 4 out of 5 weakness in her left iliopsoas and hyperesthesia in the left L3 dermatome. Lumbar spine magnetic resonance imaging (MRI) demonstrated a 24 × 23 × 24-mm well-circumscribed, T2 hyperintense, homogenously enhancing mass within the left psoas muscle. The mass was contiguous with the extraforaminal L3 nerve root and avidly contrast enhanced (Figure 1). No additional masses were seen on cervical and thoracic spine MRI. Electromyography (EMG) and nerve conduction studies were unremarkable.

Based on the imaging findings, a benign nerve sheath tumor such as schwannoma or neurofibroma was favored. A traditional anterior approach was discussed with the patient. As the bulk of the mass was within the psoas muscle, we elected for a minimally invasive lateral retroperitoneal approach.

1. Surgical Approach

A minimally invasive lateral transpsoas approach as previously described by Boah and Perin [7] was used. Briefly, the patient was placed in lateral decubitus position and C-arm fluoroscopy used to localize the appropriate vertebral level. Using O-arm neuronavigation, a vertically oriented incision was made with subsequent blunt dissection of the oblique and transverse abdominal muscles. The transversus fascia is identified and opened bluntly in order to expose the retroperitoneal fat over the level of interest. A self-retaining retractor system (Phantom XL3, TeDan Surgical Innovations, Sugar Land, TX, USA) was inserted over the surface of the psoas muscle and the exoscope (Modus V, Synaptive Medical, Toronto, ON, Canada) brought into the field for microsurgical dissection.

The psoas muscle was carefully dissected parallel with the muscle fibers in order to identify the intramuscular mass. Intraoperative neuromonitoring (IONM) consisted of continuous somatosensory evoked potentials and continuous and evoked EMG. Using direct simulation, the L3 nerve root was identified and found to be splayed over the lateral portion of the mass (Figure 2A) based on IONM. A narrow safe working window without overlying nerve was identified at the anterior aspect of the tumor. The capsule was coagulated and incised to allow for central suction aspiration and pituitary rongeur debulking. Frozen section specimens returned intraoperative as schwannoma. Unfortunately, the positioning of the overlaying nerve root did not allow for further safe debulking of the superior and lateral portions of the mass. After debulking, the nerve stimulated easily and appeared significantly decompressed. Hemostasis was achieved, the retractor system removed, and incisions closed in the usual fashion.

2. Follow-up

The patient did well postoperative, with immediate improvement in her pain and left iliopsoas strength improving to 5 out of 5. Postoperative MRI (Figure 2B) demonstrated debulking of the anterior and inferior portions of the mass, although residual tumor remained. Final pathology was consistent with schwannoma. At most recent 3-month follow-up, she continues to be

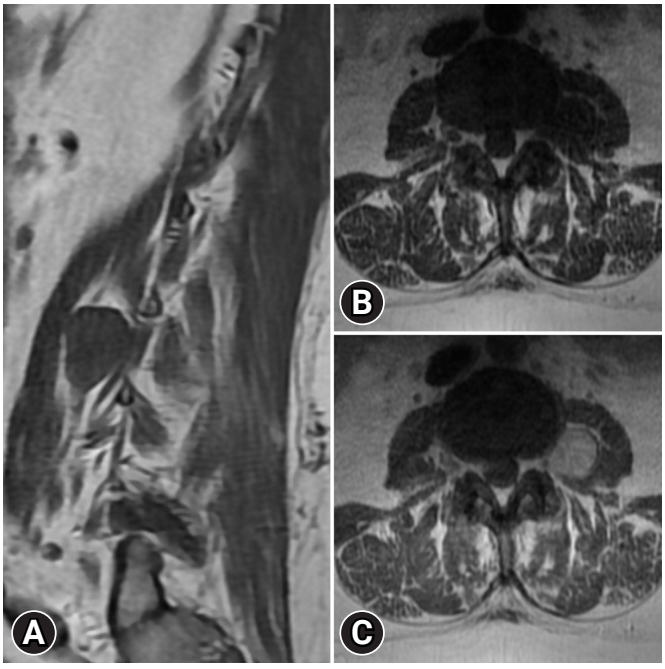

Figure 1. Preoperative imaging. Sagittal (A) and axial (B) T1-weighted lumbar spine magnetic resonance (MR) imaging demonstrating a large well-circumscribed T1 isointense mass continuous with the extraforaminal left L3 nerve, the bulk of which lies within the psoas muscle. (C) Homogeneous enhancement on gadolinium-enhanced MR images consistent with a schwannoma.

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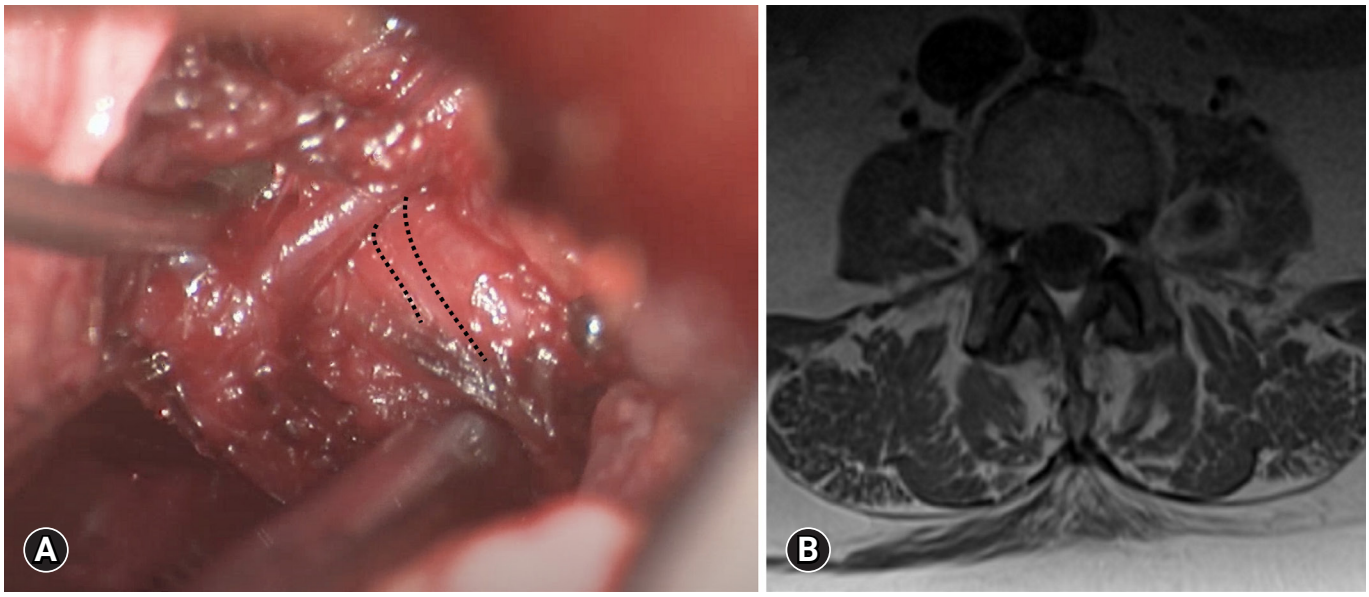

Figure 2. (A) Intraoperative photo (superior oriented left) shows the L3 nerve rootlet (dotted line) overlying tumor, which significantly limited the safe working corridor. (B) Postoperative axial gadolinium-enhanced T1-weighted lumbar spine magnetic resonance imaging showing subtotal resection with significant debulking of the anteroinferior portion of the tumor.

full strength with significant pain relief.

Informed consent was obtained from the patient prior to publication.

DISCUSSION

Extraforaminal lumbar schwannomas are an exceptionally uncommon clinical entity, representing 0.7%–4.2% of all extradural schwannomas [2,8]. Mainstay of treatment is gross total surgical resection with preservation of the involved nerve root, which is generally curative and associated with limited morbidity [9,10]. However, methodical establishment of optimal surgical strategies for this subgroup of tumors is lacking due to their rarity [1]. As such, the surgeon must consider tumor size, location, and involvement of adjacent structures when selecting a surgical approach.

The traditional approach for these tumors is an open anterior retroperitoneal approach with or without laparoscopic assistance which afford early visualization and isolation of the major vasculature. However, these anterior techniques are limited in their approach of foraminal tumors and do not allow for utilization of a stimulator probe for early identification of nerves. Midline and paraspinal posterior approaches have also been described, and involve total- or hemilaminectomy and/or total or medial facetectomy [3]. For tumors requiring extensive bony resection or those tumors with greater spinal canal or foraminal disease, a posterior approach may be suitable. Concomitant arthrodesis and instrumentation may be necessary to reduce the risk of spinal instability, further adding to surgical morbidity [3,11,12]. In recent years, a number of mini-open or MIS approaches to lumbar extraforaminal schwannomas have been described [12-16]. Minimally invasive techniques allow for less muscle and ligamentous disruption, are associated with less blood loss, and shorter postoperative length of stay, thus lessening surgical morbidity [4,15]. These methods can be of particular importance in obese patient populations that have an even greater risk of postoperative blood loss, surgical site infection and nerve injury with lumbar spine surgery [17].

There have been 4 previous reports of extraforaminal lumbar schwannomas resected via a minimally invasive lateral retroperitoneal transpsoas approach (Table 1) [5,7,13,18]. This approach, adopted from extreme lateral interbody fusion, described by Ozgur et al. [6] permits the use of directional and continuous EMG monitoring along with more direct, less traumatic exposure of extraforaminal tumors. First report of minimally invasive lateral resection of an extraforaminal lumbar plexus schwannoma was presented by Lee and Srikantha [18] in 2016. A mini-open approach achieved complete resection of a 52-mm schwannoma within the psoas muscle at L4–5, followed by L4–5 discectomy and fusion for grade 1 anterolisthesis. Postoperative, the patient had new grade 4/5 iliopsoas weakness which resolved at 3-month follow-up. Benjamin et al. [5] and Boah and Perin [7] each reported successful complete resection of smaller extraforaminal lumbar schwannomas

Table 1. Reports of minimally invasive lateral/oblique retroperitoneal approach for extraforaminal lumbar schwannomas

Study	Age/sex	Level	Maximum tumor diameter (mm)	Preoperative symptoms/deficits	Surgical management	Operative findings	Outcomes
Lee and Srikantha (2015) [18]	57/M	L4–5	52	L4 radiculopathy	Mini-open	N/A	4/5 Iliopsoas and hip pain, weakness and pain resolved at 3-mo follow-up
Benjamin et al. (2016) [5]	38/M	L4–5	10	L4 dysesthesia, 4/5 quadriceps/dorsiflexion weakness	MIS	Nerve root posterior to retractor	Normal strength and improvement in dysesthesia at 12-mo follow-up
Boah and Perin (2016) [7]	18/F	L4–5	20	L4 radiculopathy	MIS	N/A	Normal strength, mild anterior thigh numbness at 12-mo follow-up
Safaee et al. (2017) [13]	53/F	L2–3	41	L2 radiculopathy, 4+/5 iliopsoas/quadriceps weakness	MIS	No EMG activity, nerve coagulated and divided	Normal quadriceps strength, improved pain, mild anterior thigh numbness postoperative day 2
Present case	53/F	L3–4	24	L3 radiculopathy, 4/5 iliopsoas weakness	MIS	Nerve root overlying lateral tumor	Normal strength, complete resolution of pain at 3-mo follow-up

MIS, minimally invasive surgical; N/A, not available; EMG, electromyography.

without complications at 12-month follow-up. Most recently, Safaee et al. [13] reported complete resection of a 41-mm extraforaminal right L2 schwannoma. The patient's preoperative 4/5 iliopsoas and quadriceps weakness improved to 4+/5 and 5/5, respectively, with slight anterior thigh numbness at time of discharge on postoperative day 2. However, they do not provide long-term clinical follow-up.

Our case highlights important limitations of these minimally invasive techniques. Position of the parent nerve in relation to tumor cannot be reliably discerned on conventional MRI, and may only be discovered upon operative examination. Inopportune lateral splaying of the nerve can prohibit a nerve sparing gross total resection resulting in subtotal resection in order to preserve the nerve root and avoid significant functional motor status morbidity, as occurred in the case discussed by this paper. This also highlights the importance of IONM and direct neural stimulation. Splayed nerves may not appear visually distinct from tumor and lead to inadvertent sacrifice and postoperative deficit. Another undescribed limitation of this approach is body habitus and the long working corridor a large body habitus can necessitate. Despite the technical challenges that led to a subtotal resection, the patient's neurologic examination and radiculopathy improved. It is therefore reasonable to consider this type of minimally invasive approach to such pathologies when stratifying risk with the understanding that gross total resection may not always be feasible and safe.

Nevertheless, the MIS lateral transpsoas approach allowed for debulking and decompression of the nerve root with sustained symptom relief. Traditional anterior and posterior approaches were considered in our patient. Given her age and BMI, a posterior approach with hemilaminectomy and medial facetectomy was felt to present considerable risk of postoperative instability necessitating instrumentation and fusion [19]. Lateral transpsoas approaches are not without risk of injury to the lumbosacral plexus due its proximity, which moves more anteriorly at lower levels [20]. Complications are exceptionally rare and IONM further reduces rate of complications to less than 1% [21]. For select extraforaminal lumbar nerve sheath tumors, a MIS lateral retroperitoneal approach provides a direct, safe working corridor for resection and improvement of patient symptoms.

CONCLUSION

Extraforaminal lumbar schwannomas are an uncommon pathology presenting a complicated surgical paradigm. The MIS lateral transpsoas approach provides direct access for select tumors, while affording the benefits of reduced tissue disruption, blood loss, and postoperative length of hospitalization. Total tumor resection may be inhibited by body habitus and intraoperative discovery of unfavorable nerve root position in relation to tumor, thus demonstrating limitations to this approach. However, substantial nerve decompression and symptomatic relief through subtotal tumor resection may be the most suitable for benign pathologies in order to minimize morbidity in more complex cases.

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NOTES

Conflict of Interest

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Case Report

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Delayed Fungal Infection After Anterior Lateral Interbody Fusion Treated With Oblique Lateral Interbody Fusion: A Case Report and Literature Review

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This report presents a rare case of a fungal infection following an anterior lateral interbody fusion (ALIF) procedure. A 73-year-old man with rheumatoid arthritis underwent ALIF for lumbar spondylolisthesis and spinal stenosis. After surgery, he experienced severe back pain. Radiological tests showed pseudoarthrosis, osteolysis, and signs of surgical site infection. Revision surgery using oblique lateral interbody fusion (OLIF) and an allo-bone graft was performed. This addressed the complications, removed the previous cage, and provided interbody support. The patient's pain significantly decreased, and he recovered from an *Aspergillus fumigatus* infection after voriconazole treatment. Follow-up examinations confirmed the infection's resolution and the maintenance of spinal stability. It is crucial to identify fungal infections in patients on immunosuppressive drugs. The case validates the efficacy of voriconazole efficacy in treating *Aspergillus* spondylitis and the safety and effectiveness of OLIF for ALIF revision surgery.

Key Words: Fungal infection, Minimally invasive spine surgery, Oblique lateral interbody fusion, Revision surgery

INTRODUCTION

Over the past few decades, there has been notable progress in the field of minimally invasive spine surgery (MISS). MISS is known to offer several advantages, including reduced postoperative pain, faster recovery and reduced surgical site infection (SSI) due to minimal incisions and tissue manipulation [1]. Based on these advantages, MISS has become a highly preferred surgical approach for treating various spinal conditions, including degenerative, traumatic, and deformity cases [2]. However, despite its many advantages, SSI remains a significant concern for spine surgeons who prefer MISS [3]. In this article, we aim to share a unique case experience involving the revision of a patient who developed a delayed surgical site fungal infection following anterior lateral interbody fusion (ALIF). The revision procedure involved oblique lateral interbody fusion (OLIF) using an allo-bone graft.

CASE REPORT

1. Case Presentation

A 73-year-old male patient with a medical history of rheumatoid arthritis diagnosed in 2017 has been taking leflunomide, methotrexate, and hydroxychloroquine. He underwent ALIF surgery from L2 to L5 at a Gwangju Wooridul Hospital in April 2021. The purpose of the surgery was to address lumbar spondylolisthesis and spinal stenosis, which were causing

low back pain. Immediately after the operation, there were no signs of neurological deficit, and the patient experienced some improvement in low back pain. However, after approximately 6 months, the pain recurred and worsened, ultimately rendering the patient unable to walk due to severe low back pain. Initial treatment involved conservative measures to manage the symptoms, but no significant improvement was observed. Accordingly, radiological examinations, including x-ray and computed tomography (CT), were conducted. These tests confirmed a fracture of the right L5 screw and revealed the presence of pseudoarthrosis with osteolysis at the L4L/5 (Figure 1A, B). SSI was suspected, prompting the performance of contrast-enhanced magnetic resonance imaging, which identified a contrast-enhancing lesion at L5 (Figure 1C). Peripheral blood tests showed white blood cell count of 13,450/mm^3 (neutrophils 78.3%, lymphocytes 12.0%, monocytes 0.96%), erythrocyte sedimentation rate (ESR) of 37 mm/hr, and C-reactive protein (CRP) of 2.20 mg/dL. To isolate the pathogen, a CT-guided biopsy was conducted (Figure 2), and the culture test the presence of *Aspergillus fumigatus*.

2. Revision Procedure

The planned approach for the revision surgery at the site of the lesion was OLIF. Following the conventional method [4], the patient was positioned in the right lateral decubitus position, and a layer-by-layer dissection of the abdominal muscles was performed to access the retroperitoneal space. Although there were tissue adhesions resulting from the previous surgery, they were not severe. Therefore, caution was exercised during the approach to the disk space. The psoas muscle was laterally dissected to expose the disk space through the corridor where the discectomy was previously performed during ALIF (Figure 3A). During annulotomy, fluid resembling an abscess was observed, and a specimen was collected for culture testing. To ensure an adequate window, annulotomy was further performed using a Kerrison punch and pituitary rongeur forceps, followed by the removal of the previously inserted cage (Figure 3B). Then, a fibular strut was cut to match the dimensions of the disk space and inserted to provide support within the empty interbody space. An intraoperative O-arm scan confirmed the stable positioning of the graft (Figure 3C).

After allo-bone graft insertion, the patient was changed to the prone position and the screws (65 mm × 4.5 mm) and rods previously placed in L2, 3, 4, and 5 were removed and larger di-

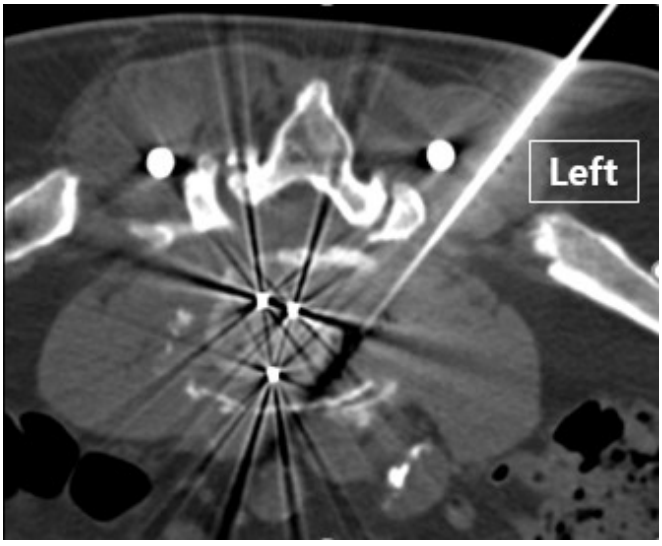

Figure 2. A computed tomography-guided biopsy procedure demonstrates the accurate placement of the needle within the L5 vertebral body for sampling.

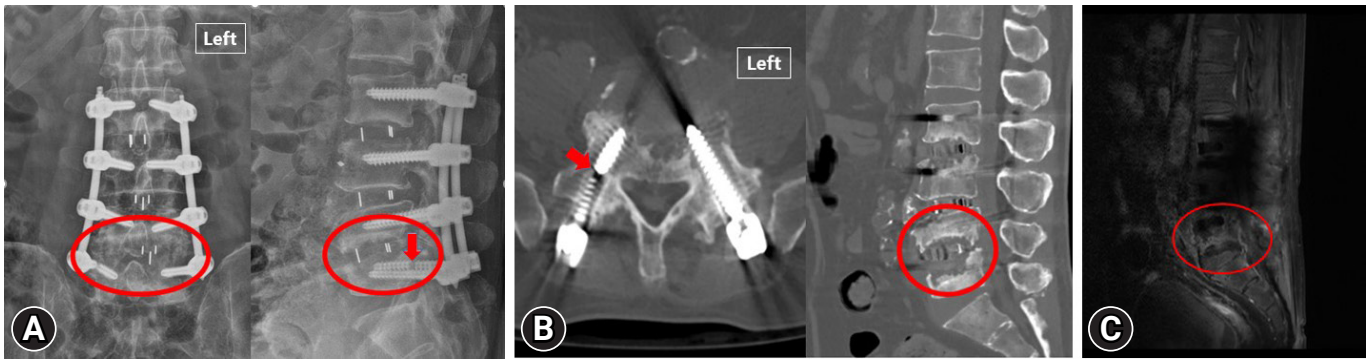

Figure 1. (A) A preoperative x-ray displays a broken screw on the right L5 level (indicated by the red arrow). Additionally, there is evidence of pseudoarthrosis with osteolytic changes at L4/5, marked by a red circle. (B) A preoperative computed tomography scan reveals a broken screw on the right L5 level (red arrow), accompanied by an osteolytic lesion (red circle). (C) Preoperative magnetic resonance imaging highlights enhanced lesions in the L5 vertebral body, indicating a suspected infection, marked with a red circle.

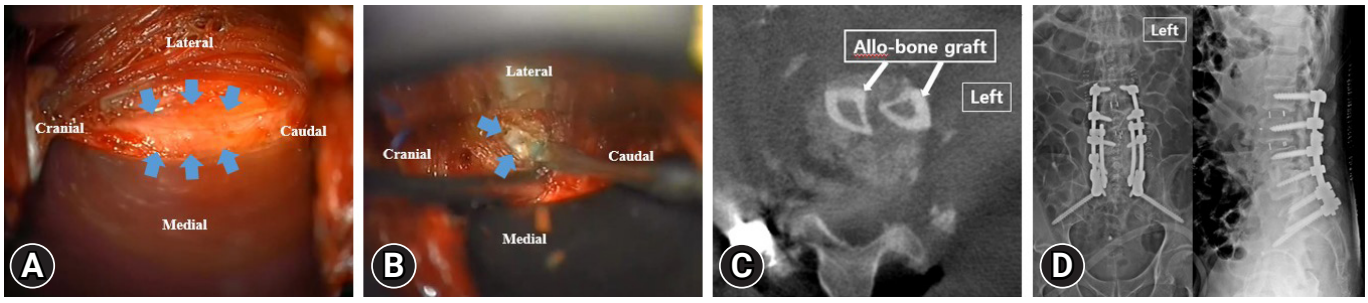

Figure 3. (A) The exposure of the disk space was achieved by laterally dissecting the psoas muscle (blue arrows). (B) Following the annulotomy procedure, the presence of a suspected abscess was confirmed, indicated by the blue arrows. (C) An intraoperative O-arm scan confirms the stable positioning of the allo-bone graft, which replaced the previously inserted cage. (D) A postoperative x-ray demonstrates the reinsertion of screws in L2–5 (right unilateral) S1–2.

ameter screws (70 mm × 5 mm) were inserted in the same path. Additional screws were inserted in S1 and S2 alar and a cross-link was used for extra stability (Figure 3D).

3. Postoperative Course

Following the surgery, the patient experienced a significant improvement in pain, and by the seventh day after the surgery, the patient was able to ambulate with the assistance of a walker. *A. fumigatus* was confirmed through culture tests conducted on the specimens obtained intraoperatively. The patient received intravenous as an antifungal treatment for 3 weeks, which was later switched to an oral agent. With antifungal agent, CRP exhibited a significant decrease, stabilizing below 0.5 (Figure 4). Subsequently, the patient was discharged. During outpatient follow-up at 6 months postsurgery, the patient demonstrated independent ambulation while wearing only a thoracolumbosacral orthosis brace. Peripheral blood tests showed normal CRP and ESR. Radiological examinations indicated well-maintained structural integrity (Figure 5), and there were no indications of infection recurrence.

DISCUSSION

MISS is widely recognized for its significantly low incidence of SSI. According to published literature, MISS has demonstrated a reduction in postoperative SSI by up to 10 times when compared to open spine surgery [5-7]. Staphylococcus aureus is commonly identified as the leading pathogen causing infections after spinal surgery [8]. Notably, cases of fungal spondylitis following MISS, as seen in our case, are extremely rare [9,10]. Previous literature reported that fungal infections can occur in the bloodstream through intravenous lines, prosthetic device implantation, or surgical procedures [11]. Fungal spondylitis tends to occur primarily in immunocompromised patients with conditions such as diabetes mellitus, undergoing chemotherapy, using chronic corticosteroids or experiencing malnutrition [10,12,13]. Given that the patient in our case had a history of continuous use of immunosuppressive agents for rheumatoid arthritis; it is presumed that the delayed fungal spondylitis occurred as a result. Therefore, it is crucial to recognize that if a delayed infection is suspected postsurgery, particularly in patients with a history of immunosuppressive agent usage, fungal infection should be considered as a possibility.

In our case, *Aspergillus* was consistently identified in both preoperative and intraoperative specimens. Spondylitis, an infection of the vertebral body, is typically caused by bacteria, but fungal infections are rare. The most common fungi causing infections are Candida, with *Aspergillus* being a less common pathogen [10,14].

Aspergillus can affect different parts of the body, including the lungs and sinuses. However, it can also rarely cause spondylitis [12,13,15]. *Aspergillus* spondylitis is a serious condition that requires immediate medical attention. Voriconazole, available in oral and intravenous forms, is considered the primary treatment for invasive aspergillosis [16]. Numerous reports have shown its effectiveness in clinical outcomes [17,18], which was also demonstrated in this case. However, careful monitoring is necessary due to its potential side effects of liver toxicity and renal dysfunction, as it maintains therapeutic concentrations in the bloodstream [19].

Allo-bone graft was chosen because it has proven to be a highly effective treatment option for spondylitis [20], and in this case, OLIF was considered as the most optimal procedure. The posterior approach was deemed unsuitable as it would not allow the insertion of larger supporting structures. Since the patient had an enlarged L4/5 interbody space caused by osteolysis, fusion using posterior approach was considered

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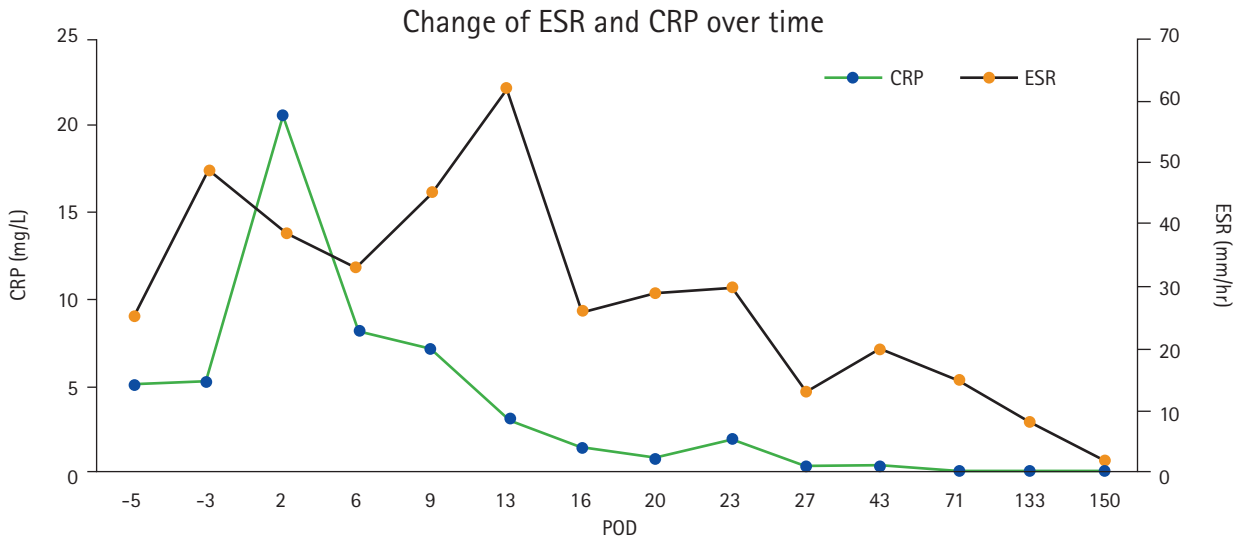

Figure 4. Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels throughout the postoperative period, extending up to a 6-month follow-up. POD, postoperative day.

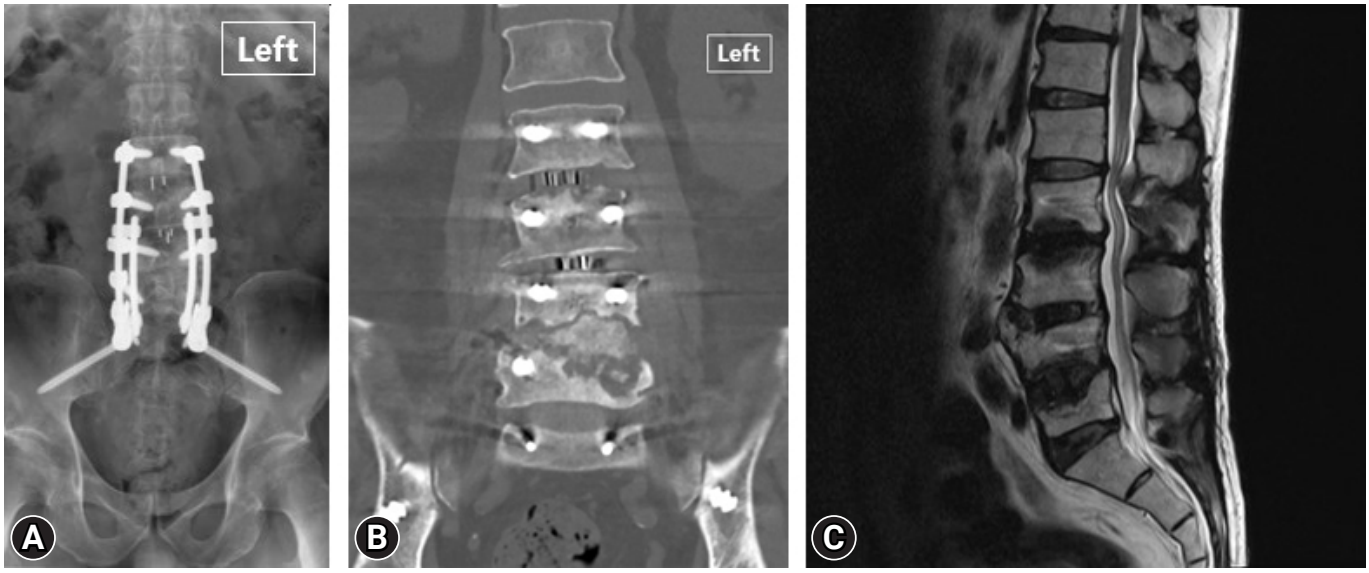

Figure 5. (A) A 6-month follow-up x-ray reveals the maintenance of stable spinal structure after revision, with no visible lytic lesions. (B) A 6-month follow-up computed tomography scan exhibits successful ongoing bone fusion, with newly formed bone surrounding the allo-bone graft, mostly replacing the previous lytic lesions. (C) Six-month follow-up magnetic resonance imaging shows no discernible signs of ongoing infection.

less suitable. Previous studies have shown higher complication rates when the anterior approach is used for revision surgery in patients who had initially undergone ALIF [21]. Similarly, performing revision OLIF after ALIF, as in this case, can pose a significant challenge for spine surgeons. However, by gaining a deeper understanding of the differences between ALIF and OLIF procedures, OLIF can be considered as an effective revision procedure. Since the ALIF corridor dissects only a portion of the medial boarder of the psoas muscle, the lateral part beyond the medial boarder is presumed to have fewer adhesions. Therefore, it is considered relatively safe to perform the OLIF by dissecting in this area (Figure 6).

CONCLUSION

In this case, we encountered a unique situation of delayed fungal spondylitis following ALIF in a patient with a history of immunosuppressive agent usage. Although fungal spondylitis

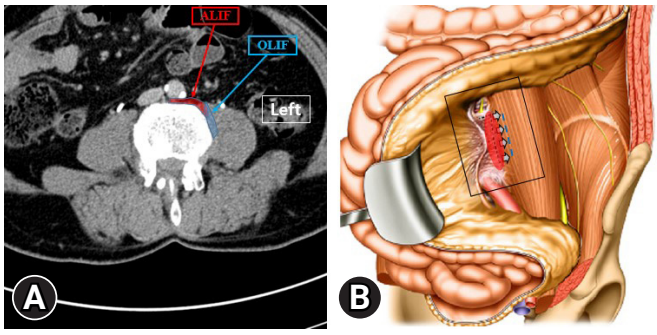

Figure 6. (A) In the conventional anterior lateral interbody fusion (ALIF) approach, the red area represents the exposed disk space. (B) The red area indicates the anticipated region of adhesion resulting from the previous ALIF procedure. It is expected that the lateral portion would have fewer adhesions. Hence, the oblique lateral interbody fusion (OLIF) approach was employed to avoid potential adhesion, as indicated by the blue dotted line.

is highly uncommon after MISS, it should be considered in the differential diagnosis when there are associated risk factors. Specifically, if the causative agent is *Aspergillus*, voriconazole could be a suitable choice for antifungal treatment. Moreover, as a revision method after ALIF, OLIF demonstrated effectiveness in this case.

NOTES

Conflict of Interest

The authors have nothing to disclose.

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1) Discussions about the findings of the research and interpretations in relation to other studies are made. It is necessary to emphasize the new and critical findings of the study, not to repeat the results of the study presented in the previous sections. The meaning and limitation of observed facts should be described, and the conclusion should be related to the objective of the study only when it is supported by the results of the research.

8. Conclusion

1) The conclusion section should include a concise statement of the major findings of the study in accordance with the study purpose.

9. References

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1. Choi S, Lim WJ, Lee MK, Ryu KS. Lumbar interbody fusion using low-dose of recombinant human bone morphogenetic protein-2 (rh-BMP2): minimum 1-year follow-up results at a single institute. J Minim Invasive Spine Surg Tech 2021;6:2-8

<Book>

1. Conover WJ. Practical Nonparametric Statistics, 2nd ed. New York : Jon Wiley & Sons, 1971, pp216-8

<Chapter in a book>

1. Ojemann RG. Surgical management of bacterial intracranial aneurysms. In: Schmideck HH, Sweet HH (eds). Operative Neurosurgical Techniques: Indications, Methods and Results, 2nd ed. Orlando : Grune & Stratton, 1988, Vol 2, pp997-1001

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1. Food and Drug Administration (FDA). Devices@FDA [Internet]. Silver Spring, MD: FDA; cited 2010 Jul 21. Available from: http://www.accessdata.fda.gov/scripts/cdrh/devicesatfda/index.cfm?pmanumber=P040006.

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