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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) and Minimally Invasive Spine Surgeons Association of Bharat (MISSAB) 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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A Multi-surgeon Robotic-guided Thoracolumbar Fusion Experience: Accuracy, Radiation, Complications, Readmissions, and Revisions of 3,874 Screws across Three Robotic Generations

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Objective: Robotic guidance provides indirect visualization of key anatomic landmarks to facilitate minimally invasive surgery (MIS) and is emerging as a reliable and accurate technique for posterior spine instrumentation. We sought to describe eight years of experience with robotic guidance at a high-volume, multi-surgeon center. We hypothesize that robotic guidance will lead to (1) low rates of complication, readmissions, and revision surgery, (2) reduced fluoroscopic radiation exposure, (3) and accurate thoracolumbar instrumentation.

Methods: A retrospective review of complications, revision surgery, and readmission rates in patients undergoing thoracolumbar fusion surgery utilizing three robotic generations. Secondary analysis was conducted comparing the three robotic generations for complications, revision surgery, accuracy, and readmission rates along with intraoperative fluoroscopic duration.

Results: A total of 628 patients (3,874 robotic-guided screws) ages 12–81 years-old (43.9% male) were included in the study. At one year, the cumulative complication incidence was 15.5% with a 10.3% incidence of surgical complications (3.7% wound, 1.2% robot-related, and 5.4% non-robot-related complications). At one year, the revision surgery incidence was 9.4%. There was no statistical difference between complications, readmission, or revision surgery after initial admission among the three robotic generations. The average intraoperative fluoroscopic duration was 53.8 seconds (11.9 seconds per screw and 17.6 seconds per instrumented level).

Conclusion: Robotic guidance in thoracolumbar instrumented fusions was associated with low complication, revision surgery, and readmission rates. Our results suggest robotic guidance can provide accurate guidance with minimal adverse events in thoracolumbar instrumentation.

Key Words: Robotic spine surgery, Robotic-guidance, Minimally invasive surgery, Minimally invasive spine surgery, Thoracolumbar fusion, Instrumented lumbar fusion

INTRODUCTION

Since the introduction of the first surgical robotic system over twenty years ago, robotic-guided surgery has become an integral tool in multiple surgical fields [1,2]. In 2004, Mazor SpineAssist® (Mazor Robotics Ltd., Caesarea, Israel) became the first

Food and Drug Administration (FDA) approved robotic-guided system in spine surgery [3]. During spine surgery, robotic guidance systems, fluoroscopy, and navigation provide indirect visualization of key anatomic landmarks and facilitate minimally invasive surgery (MIS) [3-5]. The significant benefits associated with MIS have driven considerable research and development with significant advancement between robotic generations and robotic systems [3,4].

The currently available guidance systems in spine surgery can be classified into three general categories: standard navigation-based systems with optical tracking reference markers (NAV), robotic arms combined with a NAV system (RNAV), and anatomy recognition-based robotic systems. RNAV systems utilize optical reference markers attached to the patient and a floor-mounted robotic arm registered with intraoperative 3-dimensional (3D) imaging; anatomy recognition-based robotic systems utilize bed- or patient-mounted systems fixed to bony landmarks and preoperative planning from 3D imaging. Mazor Core™ technology (MCT) (Medtronic, Minneapolis, MN, USA) utilizes automated anatomy recognition software that registers individual vertebrae on two-view intraoperative fluoroscopic imaging with preoperative 3D images and determines the patient's intraoperative location relative to the robotic system.

The current literature suggests that robotic guidance systems can be used to perform reliable and accurate thoracolumbar pedicle instrumentation [5-8]. However, significant variation between robotic technology over time and individual proprietary robotics systems introduces significant heterogeneity in the body of research. Findings related to accuracy or safety of one robotic guidance system cannot be directly attributed to other robotic guidance systems, and as such, independent studies of each system are ultimately necessary. The current study reviews the experience across three robotics systems over eight years utilizing MCT for thoracolumbar fusion surgery at a single high-volume, multi-surgeon center. We hypothesize that robotic guidance will lead to low rates of complication and revision surgery, reduced fluoroscopic radiation exposure, and accurate thoracolumbar instrumentation.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Advarra (IRB No. Pro00034175).

1. Study Design and Patient Selection

We conducted a retrospective review of robotic-guided thoracolumbar spine surgeries at a multi-surgeon, single center between July 2012 and March 2020. The experience included three robotic generations using MCT evolving over time. Renaissance® (R), Mazor X® (X), and Mazor X Stealth Edition® (MXSE) systems were utilized for robotic guidance (Medtronic, Minneapolis, MN, USA) as shown in Figure 1. R was implemented in our practice in 2012, X in 2018, and MXSE in 2019.

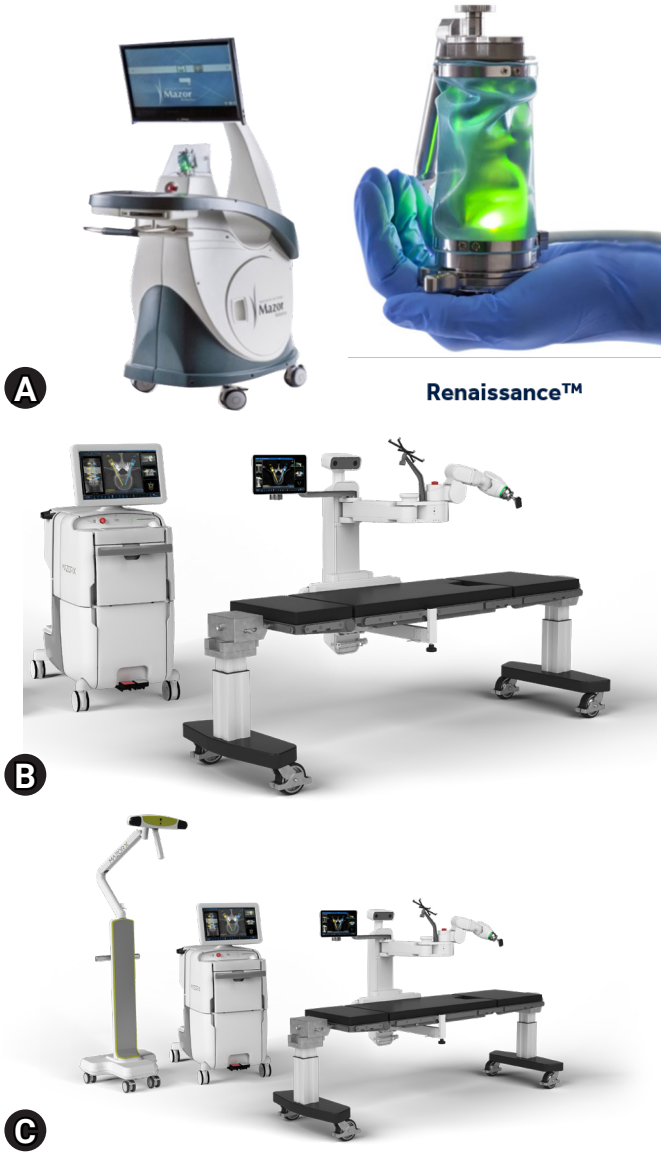

Figure 1. Images demonstrating the (A) Renaissance robotic system, (B) Mazor X robotic system, and (C) Mazor X Stealth Edition robotic system which includes the addition of the navigation camera and software upgrade.

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All consecutive adolescent and adult patients undergoing robotic-guided thoracolumbar fusions for deformity or degenerative spine conditions were included in the study. These included both primary and revision surgeries, as well as MIS and open approaches. All patients or their legal guardians signed written informed consent within the institute's Notice of Privacy Practices prior to surgery. IRB approval was granted by Advarra, a centralized IRB (Pro00034175).

2. Data Collection

Data including short- and long-term complications, revision surgery, and intraoperative fluoroscopic exposure were retrospectively collected from medical records and operative reports. Complications were subdivided into the following time periods: intraoperative, initial hospitalization, and postoperative at 30-days, 90-days, and 1-year. Intraoperative records were reviewed for the following: dural tear, estimated blood loss (EBL), neurologic deficit, other complications, and misplaced screws. For the purposes of this study, 'misplaced' was defined as any screw that required intraoperative revision of trajectory or removal as a result of pedicle screw stimulation less than 10 mA or if a breach was identified on intraoperative 3D imaging when available. Intraoperative fluoroscopic exposure was measured by intraoperative fluoroscopic duration in seconds and reported as total radiation duration, time per instrumented level, and time per robotic-executed screw. Postoperative complications were divided into surgical and medical complications. Surgical complications were subdivided into wound (including infection), robot-related (including misplaced screws and implant-related durotomy), and non-robot-related complications. Revision surgeries were reviewed at the initial admission, 30-days, 90-days, and 1-year. Medical complications occurring after 90 days postoperatively were deemed unlikely related to the robotic-guided portion of surgery and were not included.

Patient demographics, Charlson comorbidity index (CCI), body mass index (BMI), nicotine status, and primary preoperative diagnosis were collected from medical records and operative reports. Perioperative variables including EBL, number of screws, types of screws, procedure time, number of instrumented levels, length of hospital stay (LOS), and readmissions were also recorded. Postoperative computed tomography (CT) scans were available for 184 cases (a total of 1,255 screws). An independent, board-certified neuroradiologist reviewed and graded these screws for accuracy using the Gertzbein-Robbins (GR) classification [9].

3. Statistics

Descriptive statistics and cohort comparison analysis were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Fisher's exact test and chi-squared test were used to compare variables across robotic cohorts. A p-value threshold of 0.05 was used to determine statistical significance.

RESULTS

This study included a total of 3,874 robotic-guided screws in 628 patients ages 12–81 years-old (mean 51.8±13.7 years) who were 43.9% male. Patients had an average BMI of 29.8 kg/m2, CCI score of 1.2, and 7.8% were nicotine users (Table 1). R was used in 33.4% of the total cases, X in 41.1% and MXSE in 25.5%. The case majority was primary fusions (88.5%) and staged anterior/posterior procedures (88.9%). The most common surgical

Table 1. Cohort comparison (patient demographics)

	Total (N = 628)	R (N = 210)	X (N = 258)	MXSE (N = 160)	p-value
Age (yr)	51.8 ± 13.7	50.0 ± 14.6	51.9 ± 13.5	53.9 ± 12.6	0.021*
BMI (kg/m^2)	29.8 ± 6.1	29.1 ± 6.2	30.4 ± 6.0	29.9 ± 5.9	0.092
CCI	1.2 ± 1.2	1.1 ± 1.2	1.1 ± 1.2	1.4 ± 1.3	0.032*
Preoperative VAS (1–10 scale)	6.0 ± 2.3	6.3 ± 2.2	5.9 ± 2.4	5.9 ± 2.1	0.093
Sex, male	276 (43.9)	93 (44.3)	108 (41.9)	75 (46.9)	0.600
Nicotine user	49 (7.8)	13 (6.2)	26 (10.1)	10 (6.3)	0.207
1 yr VAS	3.5 ± 2.7	3.6 ± 2.6	3.4 ± 2.8	4.0 ± 2.5	0.255
VAS change (over 1 yr)	2.4 ± 3.0	2.7 ± 3.1	2.4 ± 3.0	1.8 ± 2.6	0.185
Total F/U duration (mo)	18.0 ± 16.7	30.2 ± 22.4	14.4 ± 8.0	8.0 ± 4.0	< 0.001*

Values represent the number of patients (%) or mean±standard deviation
BMI: body mass index, CCI: Charlson comorbidity index, VAS: visual analog scale, F/U: follow-up.
*Significant p-values.

indication, spondylolisthesis, accounted for 46.2% of all cases (Table 2). Of patients, 64.2% had at least 1 year of postoperative follow up with an average follow up duration of 18.0±16.3 months (Table 1).

1. Complications, Revision Surgery, and Readmissions

1) Initial Admission

A total of 9 patients (1.4%) experienced an intraoperative complication, including 8 durotomies unrelated to instrumentation and 1 episode of bradycardia. Of the 3,874 screws placed with robotic guidance, 46 (1.2%) were considered misplaced resulting in an initial robotic-guided screw placement accuracy of 98.7% (Table 3).

A total of 33 patients (5.3%) experienced a complication following surgery, during the initial admission (Table 3). Twenty-one patients (3.3%) experienced a surgical complication including: 2 hematomas (0.3%) (counted as wound complications), 6 robot-related (1.0%), and 13 non-robot-related complications (2.1%). The robot-related surgical complications were symptomatic screws identified on postoperative imaging to be malpositioned and required revision surgery during initial admission. After revision surgery, 100% achieved symptom resolution (Table 3).

Twelve patients (1.9%) required a revision surgery during the initial admission including: the 6 symptomatic malpositioned screws, 2 retroperitoneal hematomas requiring evacuation, 3 patients with radiculopathy unrelated to the instrumentation requiring posterior decompression, and 1 anterior migration of interbody implant after posterior instrumentation, requiring revision (Table 3).

2) 30 Days

At 30-days the cumulative number of patients who experienced a complication was 68 (10.8%). Cumulative surgical complications at 30 days included 14 wound (2.2%), 7 robot-related (1.1%), and 18 non-robot-related complications (2.9%). These included the following new wound complications since admission: 7 wound infections, 2 seromas, 2 retroperitoneal hematomas, and 1 epidural hematoma. One patient underwent a postoperative CT scan due to non-robot-related distal construct fracture and a screw breach was noted proximally within

Table 2. Cohort comparison (surgical variables)

	Total (N = 628)	R (N = 210)	X (N = 258)	MXSE (N = 160)	p-value
Open	177 (28.2)	48 (22.9)	71 (27.5)	58 (36.3)	0.017*
Diagnosis					
Spondylolisthesis	290 (46.2)	120 (57.1)	116 (45.0)	54 (33.8)	0.001*
DDD	121 (19.3)	40 (19.0)	51 (19.8)	30 (18.8)	
Deformity	115 (18.3)	28 (13.3)	46 (17.8)	41 (25.6)	
Stenosis	66 (10.5)	15 (7.1)	28 (10.9)	23 (14.4)	
Other	36 (5.7)	7 (3.3)	17 (6.6)	12 (7.5)	
Approach					
Posterior only	52 (8.3)	18 (8.6)	16 (6.2)	18 (11.3)	0.219
AP staged	557 (88.7)	183 (87.1)	236 (91.5)	138 (86.3)	
AP same day	18 (2.9)	9 (4.3)	6 (2.3)	3 (1.9)	
Revision surgery	72 (11.5)	26 (12.4)	27 (10.5)	19 (11.9)	0.797
No. instrumented levels	3.9 ± 3.0	3.2 ± 2.2	4.0 ± 3.0	4.6 ± 3.6	< 0.001*
Mean screws/case	6.8 ± 5.8	5.3 ± 4.5	7.2 ± 6.2	8.1 ± 6.4	< 0.001*
Mean robot screws/case	6.2 ± 2.3	4.9 ± 4.0	6.5 ± 5.5	7.3 ± 5.9	< 0.001*
Mean free-hand screws/case	0.5 ± 2.2	0.5 ± 1.7	0.3 ± 1.8	0.7 ± 3.1	0.211
Total procedure time (min)	177.7 ± 122.4	158.9 ± 106.5	179.7 ± 123.7	199.2 ± 135.7	0.007*
Net robot time (min)	35.5 ± 30.4	33.9 ± 23.5	32.2 ± 30.4	62.3 ± 49.3	< 0.001*
Total fluoro (sec)	53.8 ± 51.2	61.6 ± 70.2	55.3 ± 39.9	41.0 ± 32.3	< 0.001*
Total fluoro/screw (sec)	11.9 ± 9.8	15.6 ± 11.4	11.9 ± 8.7	7.4 ± 6.8	< 0.001*
Total fluoro per level (sec)	17.6 ± 13.5	22.4 ± 15.5	17.4 ± 11.7	11.9 ± 10.8	< 0.001*
EBL (mL)	173.8 ± 326.8	117.5 ± 207.0	196.5 ± 357.5	207.7 ± 384.9	0.012*

Values represent the number of patients (%) or mean±standard deviation
R: Renaissance, X: Mazor X, MSXE: Mazor X Stealth Edition, AP: anterior-posterior, No.: number, EBL: estimated blood loss.
*Significant p-values.

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Table 3. Complication, revision surgery, and readmission comparison

		Total (N = 628)	R (N = 210)	X (N = 258)	MXSE (N = 160)	p-value
Index admission	Intraoperative complications	9 (1.4)	3 (1.4)	2 (0.8)	4 (2.5)	0.353
	Total complications	33 (5.3)	10 (4.8)	16 (6.2)	7 (4.4)	0.664
	Medical complications	13 (2.1)	4 (1.9)	5 (1.9)	4 (2.5)	0.906
	Surgical complications	21 (3.3)	6 (2.9)	12 (4.7)	3 (1.9)	0.274
	Wound complications	2 (0.3)	1 (0.5)	1 (0.4)	0 (0.0)	0.700
	Robot-related	6 (1.0)	1 (0.5)	5 (1.9)	0 (0.0)	0.096
	Non-robot related	13 (2.0)	4 (1.9)	6 (2.3)	3 (1.9)	0.712
	Revision surgery	12 (1.9)	3 (1.4)	9 (3.5)	0 (0.0)	0.033*
30 days	Total complications	68 (10.8)	22 (10.5)	27 (10.5)	19 (11.9)	0.887
	Medical complications	32 (5.1)	10 (4.8)	13 (5.0)	9 (5.6)	0.966
	Surgical complications	38 (6.1)	13 (6.2)	15 (5.8)	10 (6.3)	0.980
	Wound complications	14 (2.2)	7 (3.3)	3 (1.2)	4 (2.5)	0.407
	Robot-related	7 (1.1)	1 (0.5)	5 (1.9)	1 (0.6)	0.384
	Non-robot related	18 (2.9)	6 (2.9)	7 (2.7)	5 (3.1)	0.828
	Revision surgery	30 (4.8)	11 (5.2)	12 (4.7)	7 (4.4)	0.809
	Readmission	24 (3.82)	11 (5.2)	6 (2.3)	7 (4.4)	0.372
90 days	Total complications	85 (13.5)	26 (12.4)	35 (13.6)	24 (15.0)	0.767
	Medical complications	36 (5.7)	10 (4.8)	14 (5.4)	12 (7.5)	0.604
	Surgical complications	55 (8.8)	17 (8.1)	23 (8.9)	15 (9.4)	0.905
	Wound complications	25 (4.0)	10 (4.8)	10 (3.9)	5 (3.1)	0.474
	Robot-related	7 (1.1)	1 (0.5)	5 (1.9)	1 (0.6)	0.229
	Non-robot related	24 (3.8)	7 (3.3)	8 (3.1)	9 (5.6)	0.383
	Revision surgery	47 (7.5)	15 (7.1)	20 (7.8)	12 (7.5)	0.970
	Readmission	41 (6.5)	15 (7.1)	14 (5.4)	12 (7.5)	0.641

Data collected cumulatively. Values represent the number of patients (%).
R: Renaissance, X: Mazor X, MSXE: Mazor X Stealth Edition.
*Significant p-values.

the construct incidentally, which was asymptomatic. This was counted as the 1 new robot-related complication because the misplaced screw was removed during the revision surgery to extend the construct distally (Table 3).

The 30-day cumulative revision surgery rate was 4.8% including: 12 wound-related incision and drainage (I&D), 1 incision and drainage for arterial line site infection, 4 decompressions, 1 revision PIF, and 1 PIF extended proximally for junctional failure. The 30-day cumulative readmission rate was 3.8%, including six medical readmissions and eighteen for revision surgery (Table 3).

3) 90 Days

The 90-day cumulative complication incidence was 13.5% (Table 3). Cumulative surgical complications included 4.0% wound, 1.1% robot-related, and 3.8% non-robot-related complications. In the 90-day period new wound complications included: 10 wound infection and 1 epidural hematoma. No new robot-related complication occurred during the 90-day follow up period (Table 3).

Eighteen patients underwent revision surgery between the 30- and 90-day marks, resulting in a 7.5% cumulative revision surgery rate. The 90-day revision surgeries included: 11 wound-related I&Ds, 5 additional decompressions, 1 ALIF revision, and 1 PIF extended distally for distal junctional failure. The cumulative readmission rate at 90 days was 6.5%. Twenty new readmissions occurred between the 30- and 90-day period, 18 for revision surgery and 2 for medical complications (Table 3).

4) 1 Year

A total of 406 patients reached a 1-year follow-up. The cumulative complication incidence for these patients was 15.5%. Surgical complications were 3.7% wound, 1.2% robot-related, and 5.4% non-robot-related cumulative complications. Between 90 days and 1 year follow-up, 10 new complications occurred that were not robot-related. These included one wound infection, five patients with radiculopathy, and four patients with prox-

imal junctional kyphosis. All ten patients underwent revision surgery resulting in a cumulative revision surgery incidence of 9.4% (Table 4).

2. Robotic Cohort Comparison

Over time, patients undergoing robotic-guided surgery were older with a higher CCI score, a greater number of instrumented levels, and more likely to require an open procedure versus MIS (Table 1, 2). As a result, total procedure time, net robot time, and number of robotic-guided screws also increased over time. There was no statistical difference between cumulative complications, readmission, or revision surgery after initial admission among the three robotic generations. MXSE cohort required no revision surgeries during the initial admission compared with 3.5% in the X cohort and 1.4% in R (p=0.033) (Table 3, 4).

3. Fluoroscopic Radiation Exposure

The average total fluoroscopic duration was 53.8 seconds. The average fluoroscopic duration per screw was 11.9 seconds per screw and 17.6 seconds per instrumented level. The mean fluoroscopic duration in the MXSE cohort was 41.0 seconds, the lowest across the three generations (vs. X: 55.3 seconds and R: 61.6 seconds, p<0.001). Over time, the evolving robotic guidance systems led to less intraoperative radiation. A statistically significant decrease in intraoperative radiation was found in the MXSE cohort compared to the X and R cohorts (Table 2).

4. Accuracy

Of the 3,874 screws, 1,255 screws had postoperative computed tomography (CT) scans available for independent review. Of the graded screws, 1,153 screws (91.9%) were classified as Gertzbein-Robbins (GR) grade A or B. There was no statistically significant difference in GR grading between the three robotic cohorts (Table 5).

DISCUSSION

Innovation in robotic guidance has been driven by a desire to improve patient safety and surgical efficacy. The current generations of robotic systems combine precise anatomic landmark identification with specialized surgical planning software to achieve this goal. The literature supports improved accuracy and reliability with robotic-guided systems in spine surgery with accuracy rates as high as 99% [10-12]. The current consensus from several systematic reviews and meta-analyses supports high accuracy rates and the potential benefits of robotic guidance; however, the current body of evidence is limited by substantial heterogeneity between systems and a lack of complication and revision surgery data [4-7,10,13,14]. The few studies evaluating complications and revision surgery focus exclusively on wound complications and revision surgery for malpositioned screws during the early postoperative period [11,15,16]. The authors seek to expand the scope of the current literature by reporting both short-term and long-term complications, revision surgery, and readmission rates at a high-vol-

Table 4. One year complication, revision surgery, and readmission comparison

		Total (N = 406)	R (N = 164)	X (N = 183)	MXSE (N = 59)	p-value
1 yr	Total complications	63 (15.5)	24 (14.6)	27 (14.8)	12 (20.3)	0.541
	Surgical complications	42 (10.3)	15 (9.2)	18 (9.8)	8 (13.6)	0.619
	Wound complications	15 (3.7)	7 (4.3)	7 (3.8)	1 (1.7)	0.662
	Robot-related	5 (1.2)	1 (0.6)	4 (2.2)	0 (0.0)	0.269
	Non-robot related	22 (5.4)	7 (4.3)	8 (4.4)	7 (11.9)	0.061
	Revision surgery	38 (9.4)	13 (7.9)	18 (9.8)	7 (11.9)	0.148

Table 5. Accuracy comparison using Gertzbein and Robbins (GR) grade

	All (N = 1,255)	R (N = 459)	X (N = 589)	MXSE (N = 207)	p-value
Grade A	73.6% (924)	74.5% (342)	73.3% (432)	72.5% (150)	0.976
Grade B	18.2% (229)	17.6% (81)	18.7% (110)	18.4% (38)	
Grade C	4.6% (58)	5.0% (23)	4.1% (24)	5.3% (11)	
Grade D	2.2% (28)	2.0% (9)	2.4% (14)	2.4% (5)	
Grade E	1.3% (16)	0.9% (4)	1.5% (9)	1.4% (3)	

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ume spine surgery center across the R, X, and MSE robotic systems.

Our results found low cumulative complication (15.5%), revision surgery (9.4%), and 90-day readmission rates (6.5%) across all three generations of robotic systems at 1 year follow up. These results are consistent with or better than the limited literature on instrumentation-related complications and revision surgery. In our study of 628 consecutive cases and 3,874 robotic-guided screws, seven patients required revision surgery for robot-related complications, an overall rate of 1.1%. Six of the seven required revision surgery during their initial admission for implant-related radiculopathy. Siccoli et al.'s [4] recent systematic review and meta-analysis comparing robotic-guided, navigation-guided, and freehand thoracolumbar pedicle screw placement was unable to draw conclusion on complication rates with robotic guidance due to lack of sufficient data. Fourteen of the 31 studies included in the systematic review reported complication rates, but none of the fourteen were determined to be high-quality studies [4]. A more recent comparison study of 46 O-arm Navigation and 39 Mazor X patients found no difference in wound-related complication rates between the two groups [17]. Another small matched cohort study reported an 8.7% 30-day complication rate with robotic-guidance, but it does not discuss what types of complications were tracked or occurred [16].

Two recent studies evaluated perioperative outcomes between robotic guidance (RG) and fluoro-guidance (FG) in adult lumbar fusions in the prospectively collected, multicenter MIS ReFRESH database [8,18]. Good et al. [8] evaluated a total of 485 patients: 374 in the RG arm and 111 in the FG arm. Patients in the RG group had a 10.4% surgical complication rate and 2.1% rate of revision surgery at 1 year compared to 35.1% and 6.3%, respectively, in the FG arm. They found patients in the FG arm were 5.8 times more likely to develop a complication (HR=5.8, 95% CI: 3.5–9.6, p<0.001), and 11.0 times more likely to require a revision surgery (HR=11.0, 95% CI 2.9–41.2, p<0.001) compared to those in the RG [8]. Liounakos et al. [18] found reduced complications and revisions in patients undergoing robotic-guided fusions. They reported an 8.02% 90-day complication rate with short segment robotic-guided fusions and 83.2% reduction in complications compared to freehand technique (p<0.001) [18].

Lieber et al. [19], utilizing the National Inpatient Sample, matched robotic-guided and conventional short-segment lumbar fusions to compare complication rates. They found a 31.9% and 8.2% complication rate for minor and major complications, respectively in the robotic-guided group. There was an overall complication rate of 36.2% in the robotic-guided group compared to 21.0% in the conventional technique group (p<0.001); statistical significance was lost after controlling for confounding factors in their multivariate analysis [19].

Staartjes et al. [13] conducted a systematic review and meta-analysis comparing revision surgery rates between robotic-guided, navigated, and freehand techniques for thoracolumbar instrumentation and reported insufficient evidence of the superiority of robotic-guidance or navigation. Variations in complication rates reported in the current literature may be attributable to differences in both complication definitions between studies and complication data collection. These differences and limited current literature prevent comparison between studies [20-22].

This study found an average total fluoroscopic duration of 53.8 seconds (11.9 seconds per screw, 17.6 seconds per instrumented level). The current literature suggests that robotic guidance reduces intraoperative fluoroscopic duration and radiation exposure compared to conventional freehand technique [5,10,12,23]. This reduction in intraoperative radiation reduces the cumulative exposure and radiation risk to surgeons and OR staff. It is well documented that cumulative exposure to radiation in spine and orthopaedic surgery increases the risk of multiple health conditions [24-27]. Robotic-guidance relies on CT or O-arm imaging which may expose the patient to higher radiation, but the risk of this limited additional exposure must be weighed against the benefit of high-resolution imaging and added accuracy and surgical precision benefits.

In a randomized control trial comparing MIS robotic-guided and fluoroscopy-guided lumbar fusions, Hyun et al. [21] found fluoroscopic time per screw was decreased four-fold in the robotic vs. fluoroscopic group (3.5 seconds vs. 13.3 seconds, respectively). Another study by Roser et al. [28] found a similar reduction in fluoroscopic duration in robotic-guided surgery when patients were randomized into fluoroscopic-guided, navigation, or robotic-guided arms.

In the current study, 91.9% of the 1,255 robotic screws with postoperative CT scans were GR Grade A or B. In the R cohort, 92.2% of screws were GR Grade A or B (vs. 92.0% and 90.8%, in the X and MSE cohorts respectively). No statistically significant difference was seen in GR Grade between the three robotic cohorts (p=0.976). The accuracy rate found in the current study is consistent with rates reported in the current literature, ranging from 90% to 100% [5,7,10,12-14].

The retrospective observational study design results in several inherent limitations. In this multi-surgeon, single-center study, differences among surgical techniques and robotic ex-

perience between surgeons may introduce unrecognized confounding. Without a control group, the current study cannot reach conclusions comparing robotic-guided instrumentation with other techniques. The goal of this study is to present a high-volume, multi-surgeon spine institute's experience with complication, revision surgery, and readmission rates in robotic-guided thoracolumbar instrumentation.

CONCLUSION

This study supports that robotic-guided thoracolumbar instrumented fusions are associated with low rates of complication, revision surgery, and readmission; high levels of screw placement accuracy; and a reduction of intraoperative radiation exposure.

NOTES

Ethical statements

IRB approval was granted by Advarra, a centralized IRB (Pro 00034175).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Clinical Article

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A Prospective Study of the Accidental Durotomies in Microendoscopic Lumbar Spine Decompression Surgeries. Incidence, Surgical Outcomes, Postoperative Patient Mobilization Protocol

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Objective: To study the incidence, risk factors, surgical outcomes of accidental durotomies (ADT) in patients of microendoscopic lumbar decompression surgeries (MLDS) and the postoperative patient mobilization protocol.

Methods: A total of 550 patients who underwent MLDS from January 2012 to march 2020 under single surgeon and single institute were included in the study and incidence of ADT risk factors like age, BMI, smoking status, diabetes mellitus, surgeon's experience were studied for the same and early mobilization protocol for all the patients was followed.

Results: Age >60 years (p=0.0062), bilateral decompression with unilateral approach, surgeons experience in the first 3 years over next 5 years (p=0.037) were the statistically significant risk factors for increased incidence of ADT. Most of the ADT were small which did not require primary repair and managed with sealants like gelfoam and fibrin glue. Postoperative recovery in JOA and ODI scores in both ADT and non ADT cohorts were same.

Conclusion: MISS has low incidence of ADT and age >60 years and surgical technique of bilateral decompression with unilateral approach and surgeons expertise are the significant risk factors. MISS also has less risk of CSF leak symptoms and pseudomeningocele formation because of limited dead space formation in the soft tissue which helps in early postoperative mobilization and reduces the duration of hospital stay.

Key Words: Accidental durotomy, Microendoscopic disectomy, Gelfoam, Cerebrospinal fluid leak, Surgeons experience

INTRODUCTION

Minimally invasive spine surgery (MISS) techniques for lumbar spine pathologies are very frequently performed in recent days. MISS techniques are associated with reduced blood loss, faster recovery and reduced postoperative morbidity while yielding similar results to open procedures [1-4]. MISS provides a narrow corridor to the spine and results in minimal tissue injury. The microendoscopic approach in lumbar spine surgery for the treatment of prolapsed intervertebral disc (PIVD) was reported by Perez-Cruet et al. [5] in 2002, following Foley and Smith's description in 1997 [6]. Non expandable tubular

retractor systems are commonly used for MISS technique lumbar spine surgery, with the tubular retractor system we can approach the spine with minimal muscle dissection and cosmetic appealing incisions, which results in decreased postoperative surgical site pain and faster recovery after surgery. Microendoscopic discectomy (MED) and minimally invasive lumbar canal decompression are the most frequently performed surgeries using tubular retractor system. Accidental durotomies (ADT) are undesirable but frequent intraoperative complications. Current review of literature says the frequency of ADT in MISS is reported to range from 3.2% to 16.7% [7,8]. Once a dural tear has occurred primary repair is difficult due to limited surgical field. Intraoperative management of an accidental durotomy, with leakage of cerebrospinal fluid (CSF), includes sealing the leakage of fluid from the intradural space. This is usually accomplished by direct suture of the dural tear, applying a sealant or combination of these modalities. Diversion of CSF flow from the durotomy by placement of lumbar drain is sometimes performed. Some surgeons also routinely place a subcutaneous drain [9]. We studied the incidence of ADT in MED and minimally invasive lumbar spine decompression surgeries, intraoperative management, complications, its impact on the surgical outcomes and the mobilization protocol of the same patients. In addition, we analyzed the risk factors related to dural tears in these surgeries.

MATERIALS AND METHODS

After receiving an approval from the local medical council ethical committee, we prospectively studied 550 patients from January 2012 to March 2020 who underwent MED and minimally invasive lumbar decompression surgeries in single institution by single surgeon. Patients presenting with neurogenic claudication and/or radicular symptoms in the lower limb either due to lumbar prolapsed intervertebral disc (PIVD) and/or lumbar canal stenosis (LCS) at the lumbar spine levels (L3-4, L4-5, L5-S1) lasting for more than six to eight weeks and who failed to respond to conservative mode of management (with bed rest, painkillers and/or epidural steroid injections) where included for the procedure. Patients with a recurrent disc herniation with or without radicular symptoms who had undergone same level surgery previously, patients who needed greater than 2 level decompression, patient with intervertebral instability (>25% intervertebral slip, >4 mm translation) on flexion and extension, upright lateral radiographs were excluded from the study. We performed a lumbar MED using tubular retractor systems for patients with lumbar PIVD using unilateral approach and for patients with lumbar canal stenosis we additionally performed a bilateral decompression using a unilateral approach. We noted patients demographic data like age, gender, height, weight, smoking status and presence of diabetes. Type of procedure and occurance of accidental duratomies were recorded. We analysed if age, body mass index (BMI), smoking, diabetes had a significant influence on the incidence of ADT. As per age patients were divided into 3 cohorts, 20–40 years, 40–60 years, and >60 years. A standard three sample test for equality of proportions was performed considering the ADT rates within the three groups. For BMI, Cohorts were made according to the WHO classification. BMI was calculated by dividing the subjects mass in kilograms (kg) by the square of the persons height in meters (BMI=kg/m^2). Patients with BMI<25 are normal weight, BMI>25 and <30 as overweight and those with BMI>30 obese. Testing for the significant differences between the BMI groups was performed using a standard three sample test for equal proportions. Testing of significant difference in between diabetics and non diabetics, smoker vs. non-smokers was performed using standard two sample test for equality of proportions.

1. Surgical Technique

All surgeries were performed under spinal anaesthesia. Patients were positioned on a radiolucent table in prone position with bolsters underneath to keep the abdomen free, head end raised and pressure points well padded. Surgeon stood on the side with dominant lower limb radicular symptoms. Under fluoroscopic guidance the lumbar spine level to be operated was identified and surface marking done. Under fluoroscopic guidance an 18-guage spinal needle placed at the spinolaminar junction of the same level to be operated. Normal saline injected to make a tract in the subcutaneous and muscular plane. 20–22 mm vertical paracentral incision taken 1 cm lateral to the midline. Subcutaneous tissue and fascia incised in the line with the skin incision. Sequential dilation done using dilators of the tubular retractor system and a 22 mm tube final docking done. In patients with paracentral disc prolapse and/or unilateral lower limb radiculopathy, unilateral laminotomy, flavectomy followed by removal of the herniated disc fragment was done. In patients with lumbar canal stenosis and/or bilateral lower limb radiculopathy, the tubular retractor was tilted medially and patient along with the operating table rotated away from the surgeon side and microscope adjusted to visualize the under surface of the spinous process, undercutting of the spinous process and contralateral lamina and contralateral

flavectomy done to complete the bilateral decompression. Any disruption in the dural integrity with or without CSF leak recognized during the surgery is considered as dural tear. In patients with accidental duratomies and CSF leak, the CSF leak was controlled using gelfoam/ fibrin glue as an onlay technique. Primary repair of the dura was not done neither was any drain placed in cases of accidental duratomies. The retractor system removed and in cases with no dural tear the wound closure consisted of approximation of lumbar fascia and subcutaneous tissue with absorbable suture material and skin closure with absorbable monocryl suture and in cases with dural tear the lumbar fascia and subcutaneous tissue approximated in the same fashion but the skin was closed in a water tight fashion using nonabsorbable ethilon sutures. The occurance and details including the type of dural tear were recorded at the time of the surgery by the attending surgeon. Patients were followed up for a minimum of 1 year after surgery, during which patients underwent clinical evaluation and MRI at 6 months interval. The clinical outcome was assessed using the modified Oswestry disability index (ODI) and Japanese Orthopaedic Association (JOA) scores for the management of low back pain [10]. Improvement in the ODI score was calculated by substracting pre-and postoperative ODI score and improvement in JOA score were evaluated by Hirabayushi's method [11].

2. Postoperative Mobilization Protocol

All patients were operated under spinal anaesthesia, so patients were awake and alert postsurgery and were directly shifted to respective wards with head of bed (HOB) at zero position. Patients with no dural tear were allowed to sit bedside and mobilized bed side 4–5 hours postoperatively once the effect of spinal anaesthesia has completely wained off. In patients with intraoperative dural tear the head end was gradually elevated to 45 degree once the effect of spinal anaesthesia is wained off and monitored for any symptoms of intracranial hypotension (ICH) like headache, nausea for 4–5 hours and if no symptoms the patients were mobilized on postoperative day 1 and if symptoms present then the patients were instructed to keep HOB at zero position until next morning and whole postoperative day 1. They were allowed to sit up in bed for diet and to ambulate for bathroom usage. Postoperative day 2 patients were revaluated and if symptoms of ICH relieved then patient mobilized and discharged, if symptoms persists patient discharged with advice of HOB at zero and limited mobilization protocol till symptoms subsides and were followed with daily teleconsultation services. Occurance of postoperative dural tear complications like ICH symptoms, meningitis, psuedomeningocele were noted.

3. Statistical Analysis

Data were analysed using IBM SPSS statistics version 22. All continuous variables were found to be normally distributed using the Kolmogorov-Smirnov test, which allowed for parametric testing. Normally distributed data were compared using Student's t-test. Nominal data were compared using the chi-squared test, and $p<0.05$ was considered statistically significant in order to identify risk factors associated with accidental durotomies.

RESULTS

Study conducted over a period of 8 years, with 550 consecutive patients which included 320 males and 230 females who underwent MED and minimally invasive lumbar decompression and patient demographics were noted (Table 1).

1. Incidence of Accidental Durotomies and Risk Factors

A total of 25 patients (14 male, 11 female; 4.54%) had intraoperative dural tear. The mean age of these patients was 56.15 years (24–86 years). Patients of age above 60 years had significantly higher dural tears than those below 60 years p-value=0.0062 (Table 2). There was no statistical difference in gender between the groups. There was no significant difference in the rate dural tears between smokers and non smokers and neither with diabetics and non diabetics (Table 3, 4). The

Table 1. Patient demographics

	Initial 3 yr	Next 5 yr
Mean age in yr (range)	56.43 (27–84)	55.9 (24–86)
Gender (M:F)	115:85 (200)	205:145 (350)
Diagnosis		
PIVD	141	240
LCS	59	110
Surgery		
ULD & ULD × 2	125	210
BLD	75	140
Average BMI (kg/m^2)	27.79	25.83
Smokers	50	80
Diabetic	98	160

M:F: male:female, PIVD: prolapsed intervertebral disc, LCS: lumbar canal stenosis, ULD: unilateral approach, BLD: unilateral approach with bilateral decompression.

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Table 2. Accidental durotomies and patient's age

Age	ADT	Total	p-value
< 60 yr	5	325	0.0062*
> 60 yr	20	225	

*p<0.05 were considered to indicate statistical significance.

technique of BLD had statistically significant higher rates of dural tears when compared to ULD both in the initial 3 years and next 5 years with p-value of 0.032 and 0.016, respectively. Among the three BMI groups there was significant difference the incidence of dural tears. Out of the total 200 patients oper-

Table 3. Accidental durotomies (ADT) vs. patient demographics (1st 3 yr)

Demographic	ADT	No ADT	Total	OR	95% CI	p-value
Age						
20–40 yr	0	33	33	-	-	-
40–60 yr	2	82	85	0.346	0.093–1.281	0.098
> 60 yr	11	71	82	5.939	1.602–22.020	0.003*
Gender				1.016	0.339–3.045	0.978
Male	8	107	115			
Female	6	79	85			
Surgery				3.273	1.053–10.169	0.032*
ULD	5	120	125			
BLD	9	66	75			
BMI						
Normal	6	48	54	2.156	0.712–6.532	0.166
Overweight	2	56	58	0.387	0.084–1.786	0.208
Obese	6	82	88	1.123	0.391–3.227	0.829
Diagnosis				1.358	0.435–4.238	0.597
PIVD	9	132	141			
LCS	5	55	60			
Smoking	4	46	50	1.088	0.326–3.263	0.891
Diabetes	5	93	98	1.482	0.479–4.592	0.493

*p<0.05 were considered to indicate statistical significance.

Table 4. Accidental durotomies (ADT) vs. patient demographics (next 5 yr)

Demographic	ADT	No ADT	Total	OR	95% CI	p-value
Age						
20–40 yr	0	66	66	-	-	-
40–60 yr	2	139	141	0.320	0.068–1.503	0.129
> 60 yr	9	134	143	6.884	1.456–32.356	0.005*
Gender				1.185	0.355–3.598	0.783
Male	6	199	205			
Female	5	140	145			
Surgery				7.145	1.520–33.586	0.016*
ULD	2	208	210			
BLD	9	131	140			
BMI						
Normal	5	151	156	1.038	0.311–3.465	0.952
Overweight	3	115	118	0.7304	0.190–2.809	0.646
Obese	3	73	76	1.366	0.354–5.281	0.650
Diagnosis				1.256	0.360–4.383	0.720
PIVD	7	233	240			
LCS	4	106	110			
Smoking	3	77	80	1.276	0.330–4.296	0.723
Diabetes	6	154	160	1.408	0.422–4.695	0.577

*p<0.05 were considered to indicate statistical significance.

ated in the initial 3 years 14 patients suffered ADT (7%) and in the next 5 years out 350 operated patients 11 had ADT (3.14%), showing a significant fall in the incidence of ADT with improvement in surgeons surgical experience (Figure 1).

2. Accidental Durotomies and Clinical Outcome

All the 25 patients with dural tear were managed intraoperatively using sealants like subcutaneous fat, gelfoam and fibrin glue. Primary repair of the dural tear was not done in any of the patients. Only 2 patients with ADT had symptoms of ICH which subsided within 2 postoperative days, it was also noted that among the other 525 patients 12 patients had symptoms of ICH without ADT probably due to the needle puncture that occurred during administration of spinal anaesthesia (Table 5). None of the patients developed meningitis nor pseudomeningocele in 6 month follow-up MRI. Postoperatively patients were assessed with modified Japanese association score recovery rate and were 73.8% and 76.3% among patients with ADT and patients without ADT respectively, improvement in the ODI score were also noted which was 39.5 and 37.5, respectively in ADT and non ADT patients. No statistically significant differ-

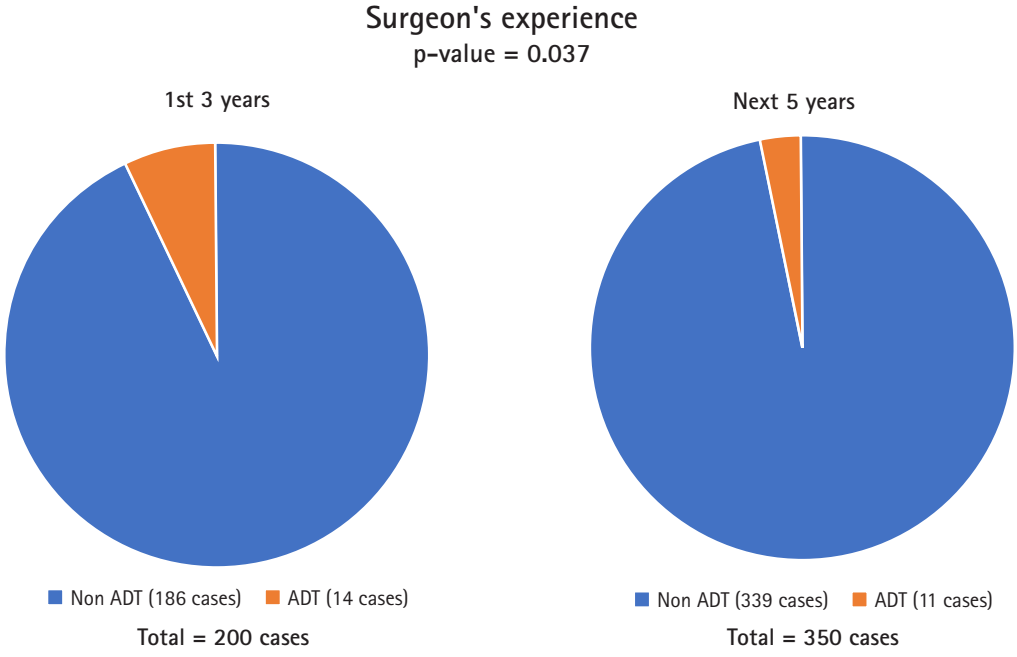

Figure 1. Accidental durotomies and surgeon's experience.

Table 5. Accidental durotomies and clinical outcome and complications

	ADT (n = 25)	No ADT (n = 25)	p-value
JOA score			
Preoperative (range)	Average = 12.6 (4–20)	Average = 13 (4–20)	0.668
Postoperative (range)	Average = 24.7 (20–29)	Average = 25.2 (22–29)	0.450
Recovery rate (%)	73.8	76.3	0.393
ODI score			
Preoperative (range)	Average = 54.8 (20–89)	Average = 52.3 (19–85)	0.499
Postoperative (range)	Average = 15.3 (4–29)	Average = 14.8 (0–33)	0.710
Improvement (average)	39.5	37.5	0.620
	ADT (n = 25)	**No ADT (n = 525)**	**p-value**
Complications			
Intra-cranial hypotension (ICH)	2	12	0.076
Meningitis	0	0	-
Pseudomeningocele	0	0	-

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ence in the recovery rate of m JOA and improvement range of ODI was noted in the 2 groups.

DISCUSSION

Accidental duratomies are frequent intraoperative complications in lumbar spine surgery. As per the literature the incidence is around 9% to 14% in open lumbar surgeries [7,8], 6.3% in MISS procedure [12]. In our study which included 550 patients total 25 patients (4.54%) had intraoperative dural tear. The prospective design and large sample size were the strength of the study. In our study we noted that incidence of ADT significantly reduced in the later 5 years of the study than the initial 3 years showing that the surgeons experience plays a major role in incidence of ADT. Lack of stereoscopic vision and poor depth perception in the initial days of surgeons practice might be one of the reason for higher incidence of ADT [13,14], indicating a steep learning curve to master the technique. We analysed some of the readily available parameters like age, BMI, smoking status and diabetes mellitus (DM). Increasing age had a significant correlation with the incidence of dural tear, probably due to thin duramater caused by ageing and frequent adhesions seen between the duramatar and surrounding tissue in elderly patients with LCS. With the ageing process the yellow ligament degeneration increases and its elasticity is lost, resulting in the deposition of calcium crystals in the yellow ligament during the bone formation process leading to its ossification [15]. Epstein [7] found a marked association between these ossified yellow ligament and ADT. In our study we noted that dural tear mainly occurred during contralateral decompression specifically while undercutting the spinous process and during contralateral laminotomy and flavectomy which can be explained because of the loss of elasticity of the flavum and adhesions between the dura and flavum and also the surgical expertise required. It is a well known fact that smoking and DM lead to poor outcomes after spine surgery because of increased risk of surgical site infections, wound healing disorders and more reoperations [16,17]. DM is a known non-genetic risk factor in the pathophysiology of ossification of posterior longitudinal ligament (OPLL) [18], but the role of both smoking and DM in the degeneration of ligamentum flavum is not well studied. In our study the correlation between smoking and DM with the incidence of ADT was statistically insignificant. Cole and Jackson [19] performed minimally invasive lumbar discectomies in 32 obese patients, ADT were the most common complication at a rate of 9.4% and they concluded that the higher rate of ADT was related to the longer working area in the obese patients. In contrast we found no significant correlation between ADT and all 3 BMI groups. Our experience during the course of the study was that a minimal invasive technique using tubular retractors and microscopic enhanced vision avoids difficult dissection through the fat plane in open surgery and gives a precise working field and clear distinction of tissues due to enhanced microscopic vision. We recommend a minimal invasive technique for spine surgery over open technique in obese patients. Accidental durotomies can lead to persistant CSF leakage leading to formation of CSF fistula, pseudomeningocele, symptoms of ICH like nausea and postural headache, back pain, intracranial hemorrhage and meningitis [20,21]. Most of the authors agree that the dural tear has to be repaired primarly [22]. But small working space available by using tubular retractor system in MISS makes the primary dural repair difficult. In our study we noted that most of the dural tear were small and could be managed with overlay sealants like subcutaneous fat, fibrin glue, gelfoam. All 25 patients who suffered ADT were managed intraoperatively using fibrin glue and gel foam no primary dural repair done. We also found that some of the patients without intraoperative ADT also developed ICH symptoms which explained due to needle puncture during the administration of spinal anaesthesia (SA). Thus even if ADT does occur in MISS, it is less likely to cause sequelae because in the MISS surgical approach the paraspinal muscles are not dissected and they slip back to their original position once the tubular retractor system is removed resulting in minimal dead space available for CSF accumulation thus preventing the formation of CSF fistula and pseudomeningocele [12,23]. We agree with authors [12,20] and do not use drain in MISS. Early mobilization is recomemded in elective spine surgery to avoid complications like venous thromboembolism [24]. We mobilized all are patients including the patients with ADT and no ICH symtoms on postoperative day 1 and maximum postoperative day 2 for patients with ADT and ICH symptoms. Very few patients required HOB at zero and limited mobilization till postoperative day 3. We therefore agree with Ruban and O'Toole [20] and Than et al. [12] for within 24 hours early mobilization protocol after MISS. This early mobilization protocol prevents postoperative deep venous thrombosis and reduces the length of hospital stay.

CONCLUSION

MISS has low incidence of ADT and age >60 years and surgical technique of bilateral decompression with unilateral approach and surgeons expertise are the significant risk factors. MISS also has less risk of CSF leak symptoms and pseudome-

ningocele formation because of limited dead space formation in the soft tissue which inturn helps in early postoperative mobilization and reduces the duration of hospital stay.

NOTES

Ethical statements

The study was received an approval from the local medical council ethical committee.

Conflicts of interest

No potential conflict of interest relevant to this article.

Authors' contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Dr. Abhijith Shetty and Dr. Vishal Kundnani. The first draft of the manuscript was written by Dr. Abhijith Shetty and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Clinical Article

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Comparative Study of the Differences in Radiologic Results for Percutaneous Endoscopic Lumbar Foraminotomy and Microscopic or Micro-endoscopic Lumbar Foraminotomy

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Objective: Lumbar foraminal stenosis is a common pathology that causes back pain and radiculopathy. Percutaneous endoscopic lumbar foraminotomy (PELF) is a minimally invasive surgical procedure reported to be effective in the treatment of foraminal stenosis; however, no studies have been conducted that compare the on radiographic results of PELF and conventional techniques for the treatment of foraminal stenosis, such as microscopic foraminotomy and micro-endoscopic foraminotomy. This study aimed to report postoperative changes in the lumbar foraminal parameters on computed tomography (CT) after PELF and to compare the radiological efficacy of the PELF technique with that of the conventional techniques.

Methods: Radiographic evaluation of the neuroforamen was based on CT scans taken preoperatively and 3 months postoperatively in the PELF and conventional groups. The Japanese Orthopaedic Association (JOA) score for back pain, visual analog scale (VAS), and JOA back pain evaluation questionnaire (JOABPEQ) were evaluated preoperatively and at 3 months postoperatively in the PELF group.

Results: The PELF and conventional groups comprised 21 and 17 patients, respectively. In the PELF group, the JOA score, VAS of back pain, and JOABPEQ of low back pain showed significant improvement. There were significant increases in the foraminal area, superior foraminal width (SFW), and middle foraminal width (MFW). Additional radiological evaluation for patients who underwent microscopic or micro-endoscopic lumbar foraminotomy was almost equivalent.

Conclusion: Percutaneous endoscopic lumbar foraminotomy is a minimally invasive technique that is as effective as conventional techniques for the treatment of foraminal stenosis.

Key Words: Percutaneous endoscopy, Foraminotomy, Foraminal stenosis

INTRODUCTION

Lumbar foraminal stenosis is a common pathology that causes radiculopathy and back pain. Conventional surgical methods for the treatment of lumbar foraminal stenosis, categorized as microscopic or micro-endoscopic lumbar foraminotomy, have been the gold standard [1].

Recently, minimally invasive spinal surgical methods have

been developed to improve preservation of the surrounding anatomical structures. Previous randomized controlled studies have reported the effectiveness of percutaneous endoscopic lumbar discectomy [2,3]. Some authors have reported good clinical results in patients with foraminal stenosis treated with percutaneous endoscopic lumbar foraminotomy (PELF) [4]. To our knowledge, no studies have been conducted on radiographic assessments comparing PELF with conventional techniques such as microscopic foraminotomy and micro-endoscopic foraminotomy.

The aims of this study were to report postoperative changes in lumbar foraminal parameters on computed tomography (CT) after PELF and to compare the radiological efficacy of the PELF technique with that of conventional techniques, such as microscopic and micro-endoscopic foraminotomy.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board of Izumi City General Hospital (No. 20-J25).

1. Patient Population

All the study participants provided informed consent. This study included patients who underwent PELF at our institution between June 2019 and November 2020 and were followed up for more than 3 months postoperatively. Patients with radicular pain and signs of radiculopathy with imaging studies showing foraminal stenosis at the level and side corresponding to the patient's symptoms were included in this study, and patients with definitive segmental instability were excluded. Patients who underwent either microscopic or micro-endoscopic lumbar foraminotomy at our institution between 2008 and 2018 were assigned to the conventional group, which was the control group.

2. Surgical Procedure (Percutaneous Endoscopic Lumbar Foraminotomy)

The procedure was performed under general anesthesia using motor-evoked potentials. The patient was placed in the prone position on a radiolucent table. An 8-mm transverse skin incision was made 5–7 cm lateral to the midline. A spinal needle was inserted toward the lateral surface of the facet joint using X-ray fluoroscopy. An obturator was inserted over the guidewire, which was passed through the needle, and fixed to the foramen. The main aspect of this surgery was removal of the hypertrophied part of the facet using an ultra-thin high-speed burr [5]. Foraminal unroofing was performed until the ligamentum flavum, and epidural fat began to appear (Figure 1, 2).

3. Clinical Evaluation

The Japanese Orthopaedic Association (JOA) score for back pain (on a scale of 0=worst to 29 points=best) was recorded preoperatively and at 3 months postoperatively [6]. Two patient-oriented questionnaires were taken, which included questions on the pain and quality of life of the patients. The scores of these, along with those for the visual analog scale (VAS) score for back pain, leg pain, and leg numbness [7], and the JOA Back Pain Evaluation Questionnaire (JOABPEQ), were evaluated preoperatively and 3 months postoperatively [8]. The JOABPEQ has five functional scores for the following domains: lower back pain, lumbar function, walking ability, social life function, and mental health [9]. Clinical evaluation was performed only for the PELF group.

4. Radiographic Evaluation

Radiographic evaluation of the neuroforamen was performed using the CT scans that were taken preoperatively for all patients for surgical planning and taken 3 months postoperatively for the evaluation of the decompression of foraminal stenosis. The images were reconstructed as sagittal slices after examining the 1.0 mm axial CT scans. According to the method described by Ahn et al. [10], the parameters of neuroforamen were defined as follows: "Foraminal area (FA) refers to the cross-sectional area at the slice that shows the maximum stenosis on sagittal section; foraminal height (FH) refers to the maximum distance between the inferior margin of the pedicle of the superior vertebra and the superior margin of the pedicle of the inferior vertebra; superior foraminal width (SFW) refers to the maximum anteroposterior width in the superior parts of the foramen; middle foraminal width (MFW) refers to the width of the central part of the foramen measured at the level of the middle height of the disc" [10] (Figure 3). The parameters of the neuroforamen were measured by two spine surgeons.

5. Statistical Analysis

All analyses were performed using the Microsoft Excel 365 software. Statistical significance was set at $p<0.05$. We com-

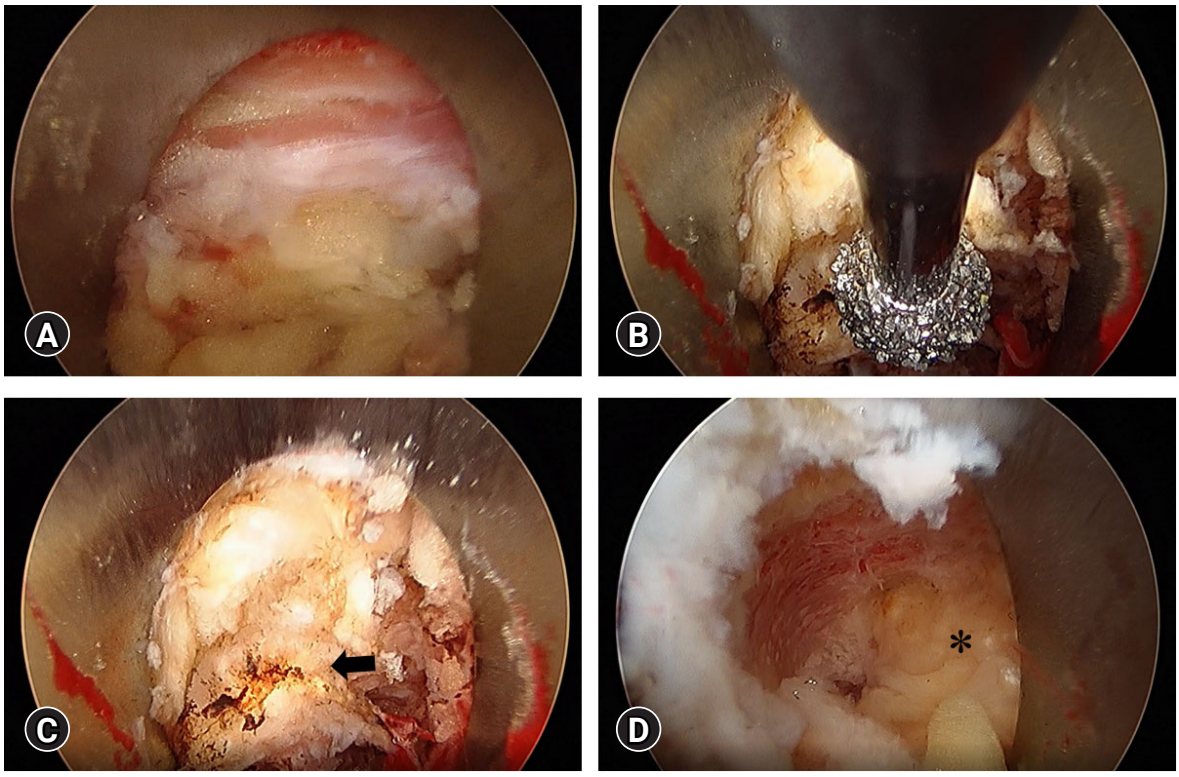

Figure 1. Endoscopic views of the surgical procedures. (A) The first endoscopic view reveals connective tissue, fat and capsular ligaments. (B) Arrow shows the hypertrophied part of the facet. (C) Removing the hypertrophied part of the facet using an ultra-thin high-speed burr. (D) Foraminal unroofing was performed until the ligamentum flavum (asterisk) appeared.

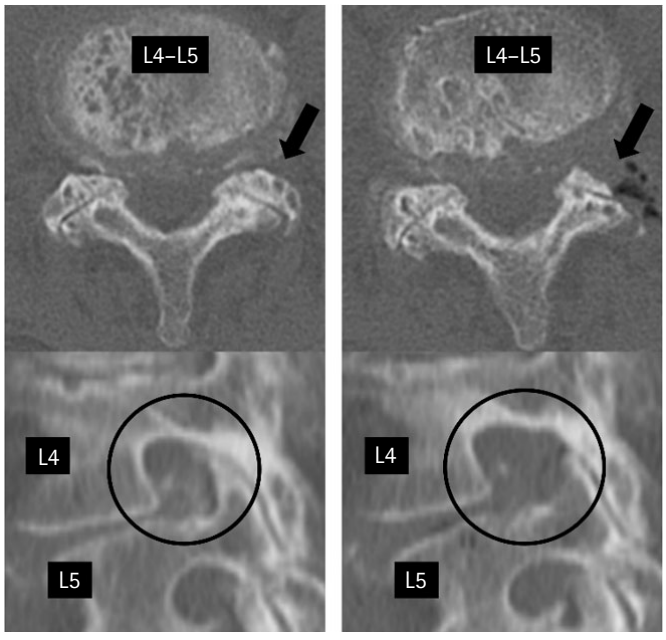

Figure 2. Computed tomography findings in an 81-year-old female who underwent percutaneous endoscopic lumbar foraminotomy at L4–L5. The location of the foraminotomy is shown on the axial slice (arrows) and sagittal slice (circles).

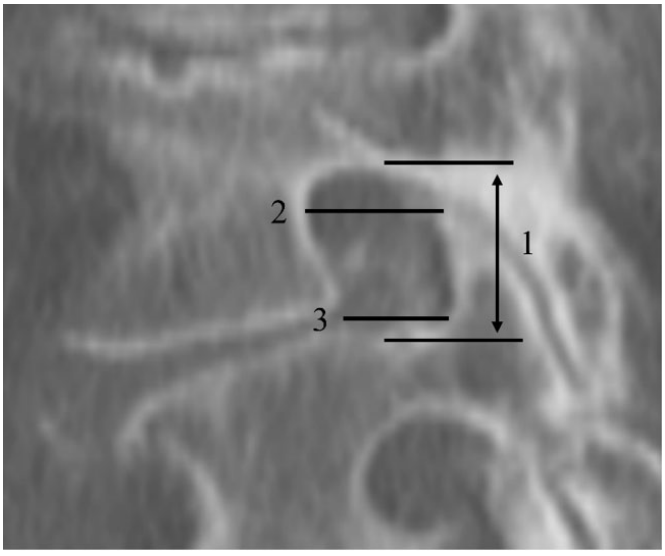

Figure 3. Measurement of foraminal dimensions on sagittal lumbar CT images. 1: Foraminal height (FH), 2: Superior foraminal width (SFW), 3: Middle foraminal width (MFW).

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pared preoperative and postoperative foraminal parameters using the Mann–Whitney U-test and performed Spearman's rank correlation analysis to assess interobserver agreement.

RESULTS

1. Demographics and Clinical Results

The PELF group consisted of 21 patients (7 men, 14 women; mean age at surgery 74.1±7.1 years), while the conventional group consisted of 17 patients (6 men, 11 women; mean age at surgery, 71.6±10.0 years). The following lumbar levels (L) were operated upon in the PELF group: L2/3 (n=1), L3/4 (n=6), L4/5 (n=20), and L5/S, (n=7) and L3/4 (n=2), L4/5 (n=7), and L5/S (n=10) in the conventional group. Operation time per neuroforamen and intraoperative blood loss showed no significant difference between the 2 groups. The baseline characteristics of the participants assigned to each treatment group are presented in Table 1.

The postoperative values for the JOA score, VAS score for back pain, and JOABPEQ score for lower back pain were significantly different from the preoperative values; however, VAS scores for leg pain, leg numbness, and the other components of JOABPEQ showed no significant differences postoperatively (Table 2).

2. Foraminal Area

The mean FA had increased in both the PELF group and conventional groups (p<0.01) (Table 3). The changes in the FA between the PELF and conventional groups showed no significant postoperative differences (Table 4). Interobserver agreement, which was measured pre- and postoperatively, was strong in the PELF group and moderate in the conventional group (Table 5).

3. Foraminal Height and Width

The changes in FH, mean SFW and mean MFW for both groups are shown in Table 3 and 4. The differences in the SFW and MFW between the PELF and conventional groups were

Table 1. Patient demographics

	PELF	Conventional
Total number	21	17
Micro-endoscope		9
Microscope		8
Average age (yr)	74.1±7.1	71.6±10.0
Sex (male)	7 (66.6%)	6 (41.1%)
Operated level		
L2/3	1	0
L3/4	6	2
L4/5	20	7
L5/S	7	10
Operated neuroforamen	34	19
Operating time per neuroforamen (min)	51.5±14.2	49.2±20.6
Intraoperative blood loss (mL)	7.9±7.0	12.5±4.0

Table 2. The change in clinical outcomes at 3 months after percutaneous endoscopic lumbar foraminotomy

	Preoperative	Postoperative	p-value
JOA score	14.3±2.4	22.4±1.6	<0.01
VAS			
Back pain	71±27	43±31	0.02
Leg pain	71±31	48±31	0.11
Leg numbness	65±35	37±28	0.14
JOABPEQ			
Low back pain	23±27	41±33	0.03
Lumbar function	40±30	49±30	0.29
Walking ability	24±23	33±32	0.29
Social life function	28±19	34±17	0.14
Mental health	34±23	40±22	0.39

JOA score: lumbar Japanese Orthopedic Association score, VAS: visual analog scale, JOABPEQ: Japanese Orthopedic Association Back Pain Evaluation Questionnaire.

Table 3. Radiographic evaluation of the neuroforamen on CT; pre- and postoperative foraminal parameters

	PELF			Conventional		
	Preoperative	Postoperative	p-value	Preoperative	Postoperative	p-value
FA	112.7±28.8	177.0±45.4	<0.01	137.3±32.5	200.5±38.8	<0.01
FH	15.4±3.1	16.1±2.9	0.35	14.7±3.4	15.4±3.0	0.51
SFW	9.0±1.9	14.0±2.9	<0.01	11.3±2.0	14.5±2.4	<0.01
MFW	6.9±2.1	11.5±2.9	<0.01	7.9±1.6	10.7±2.9	<0.01

FA: foraminal area, FH: foraminal height, SFW: superior foraminal width, MFW: middle foraminal width, PELF: percutaneous endoscopic lumbar foraminotomy.

Table 4. The changes in the foraminal parameters

	Difference (%)		p-value
	PELF	Conventional	
FA	54	49	0.23
FH	4	7	0.62
SFW	55	29	0.003
MFW	67	35	0.02

FA: foraminal area, FH: foraminal height, SFW: superior foraminal width, MFW: middle foraminal width, PELF: percutaneous endoscopic lumbar foraminotomy.

Table 5. Interobserver agreement of foraminal parameters

Measurement	Status	FA	FH	SFW	MFW
PELF	Preoperative	0.72	0.69	0.61	0.79
	Postoperative	0.71	0.61	0.68	0.74
Conventional	Preoperative	0.67	0.63	0.69	0.73
	Postoperative	0.68	0.65	0.64	0.72

Reliability analysis (ρ), strength of interobserver agreement: ρ>0.90 (very strong), 0.90 ≥ρ> 0.70 (strong), 0.70 ≥ρ> 0.40 (moderate), 0.40 ≥ρ> 0.20 (weak).
FA: foraminal area, FH: foraminal height, SFW: superior foraminal width, MFW: middle foraminal width, PELF: percutaneous endoscopic lumbar foraminotomy.

statistically significant (Table 4). While pre- and postoperative interobserver agreement was strong between the PELF and conventional groups for MFW measurement, it was moderate in both groups for FH and SFW measurement (Table 5).

DISCUSSION

Our study is the first study that compares the differences in lumbar foraminal parameters measured after percutaneous endoscopic lumbar foraminotomy and conventional surgery. It demonstrated that the changes in the SFW and MFW were significantly different in the PELF and conventional groups; however, the differences in postoperative FH and FA between the two groups were not significant. A previous cadaveric study showed that percutaneous endoscopic lumbar foraminotomy achieved an average 56.1% increase in FA [11], which is in accordance with our clinical results, which showed a 54% increase in foraminal area. The PELF technique uses a tubular retractor with a diameter of 8 mm, which is difficult to use because of the restricted operatory working space, and it limits the visual field [12]. On the other hand, the microendoscopic laminotomy (MEL) technique uses a tubular retractor with a diameter of 16 mm, which makes tilting it during surgery difficult because of its larger diameter compared to the tubular retractor used in the PELF technique. Furthermore, the MEL and PELF techniques using an oblique-view lens facilitate access to the foramen and decompression of the FA, which is not possible during microscopic lumbar foraminotomy. Thus, PELF is as effective as conventional surgical procedures for foraminal decompression.

Our study also demonstrated that the FA, SFW, and MFW significantly increased postoperatively in both the PELF and conventional groups, while FH remained unchanged. Our surgical plan caused this; we ensured that lumbar foraminotomy for foraminal stenosis was focused on decompression in the anteroposterior direction rather than in the craniocaudal direction.

Sairyo et al. [5] reported that partial pediculectomy decreased the lumbar facet contact area in patients with foraminal stenosis who underwent PELF and resulted in segmental surgical instability. Therefore, the PELF technique should be focused on removing the hypertrophied part of the facet and preventing segmental lumbar instability.

In our study, the JOA score, VAS score for back pain, and JOABPEQ score for lower back pain improved significantly after PELF. Ahn et al. [4] described a PELF and reported that 91% of the patients achieved good or excellent outcomes using the Oswestry disability index. Yoshimoto et al. [13] also reported that foraminal decompression alone had good outcomes, potentially eliminating the need for fusion surgery. Although the present study demonstrated that operation time per neuroforamen and intraoperative blood loss showed no significant difference between the 2 groups, the percutaneous endoscopic technique preserves the muscles and spinal structures, with patients of this technique recovering faster than those who undergo surgery using the conventional techniques [14]. Even though the PELF technique has a steep learning curve [15], it is gaining popularity as a minimally invasive surgery for foraminal stenosis with good outcomes.

1. Interobserver Agreement

In both the PELF and conventional groups, preoperative and postoperative foraminal parameters showed strong or moderate interobserver agreement, showing that effective foraminal decompression can be achieved using both PELF and conventional procedures.

2. Limitations of the Study

This study had several limitations. First, the duration of follow-up was short, and the long-term results of these proce-

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dures were unclear. Second, we performed the microscopic and micro-endoscopic lumbar foraminotomies in 2008 and could not acquire the clinical outcomes and complications in the conventional group from the patient charts; therefore, our study compared only the radiographic evaluations of the neuroforamen between the PELF and conventional groups. Third, the retrospective study design makes it difficult to exclude bias regarding patient demographics.

CONCLUSION

Our study showed that PELF achieved foraminal decompression as effectively as the conventional technique. Percutaneous endoscopic lumbar foraminotomy should be the preferred surgical technique in the treatment of foraminal stenosis, as it is minimally invasive and has a favorable outcome.

NOTES

Ethical statements

The study protocol was approved by the institutional review board of Izumi City General Hospital (No.20-J25).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Clinical Article

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Far-Lateral Cervical Approach as a Minimally Invasive Technique for Excision of Upper Cervical Anterolateral and Anterior Meningiomas and Dumbbell Schwannomas: Technical Report and Case Series

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Objective: To demonstrate the details of the far-lateral approach (FLA) as a minimally invasive technique for the excision of the upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas, and to assess the clinical and radiological outcomes.

Methods: In this technical report and case series we report the FLA technique and patients who underwent the FLA for C1-C4 anterolateral and anterior meningiomas and dumbbell schwannomas between June 2007 and June 2020. All patients' relative preoperative demographic, clinical, radiographic, operative, histopathological, and perioperative complications and follow-up clinical and radiographic data were reported.

Results: A total of 19 patients including 12 females and 7 males with a mean age 56.7±17.6 years and mean duration of symptoms 12.8±12.3 months were reported. 9 patients with anterolateral meningiomas, 5 with anterior meningiomas, and 5 with dumbbell schwannomas underwent uneventful FLA procedures. Gross total resection of tumors was reported in 17 patients (89.5%). Preoperative JOA score was normal in ten, grade-I in five, and grade-II in 4 patients, while at the last follow-up it improved to normal in seventeen and grade-I in two patients. Reported postoperative JOA scores at 6 months and at the last follow-up showed that all patients improved at least one grade on JOA scores. There was CSF leak in three patients and superficial wound infection in one.

Conclusion: Our results advocate the far-lateral cervical approach as a minimally invasive technique in the resection of the upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas as a safe and effective technique.

Key Words: Spine, Far-lateral, Minimal invasive, Cervical, Meningioma, Schwannoma

INTRODUCTION

Intradural extramedullary upper cervical tumors are mostly benign for which advances in imaging modalities and recent microsurgical techniques yielded better clinical outcome and prognosis [1,2]. Most of these tumors are meningiomas and

schwannomas. Although they are benign lesions, they represent a surgical challenge, particularly the anterolateral or anterior lesions representing 55% of cervical meningiomas [1] and hourglass or dumbbell lesions representing 50% of cervical schwannomas [3-5]. As the goal of surgery is total resection with preservation of function, stability, and acceptable morbidity, several surgical techniques were introduced. The posterior midline, far-lateral approach (FLA), posterior unilateral hemilaminectomy, and rarely the anterior approaches are selected to be used depending on either the location of the tumors or the preference and experience of the surgeon [5-10]. While the first and fourth techniques are conventional, the second and third are considered minimally invasive techniques.

Although the posterior midline approach is standard and familiar to most surgeons, it carries the risk of cord manipulation and affecting cervical spine muscle stability. Meanwhile, the FLA is direct surgical access with low or no risk of cord manipulation, preserving cervical spine stability, muscles, and ligaments thus considered minimally invasive, and finally ensuring smooth total tumor removal. The FLA had been designed first for foramen magnum lesions by George et al. [11] and then extended by Salas et al. [12] who introduced a variety of technical modifications or variations to suit different pathologies, and finally, it has been extended to the upper cervical spine down to C4 by other surgeons [1,7,13].

Few series in the literature have focused only on managing the upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas using the FLA. Therefore, the primary purpose of the current study is to demonstrate the surgical details of the technique of the FLA as a minimally invasive technique for excision of the upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas. The secondary purpose is to assess the clinical and radiological outcomes in patients who underwent surgery.

MATERIALS AND METHODS

This study has been approved by our Institutional Ethical and Research Review Board (IRB No. 4616#).

In this technical report and retrospective case series, we report our technique that has been performed on patients who underwent surgery using the FLA for upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas. Patients with tumors extending from C1 to C4, with complete clinical, radiographic, and contact data and those who complete at least one-year follow-up were included in this report. This study has been carried out at the spine unit of Neurosurgical Department, Suez Canal University Hospital. Our hospital records were reviewed through the period from 2007 to 2020 searching for all patients that have been operated on via the FLA for upper cervical lesions. Patients treated through other approaches, other tumor locations, other pathologies, and foramen magnum tumors and those with incomplete data were excluded. Nineteen patients were eligible for reporting in this study after the exclusion of 7 patients due to incomplete data and/or follow-up.

Surgical excision of tumors was categorized as gross total resection (GTR) when grossly excised, subtotal resection (STR) when some tumor remnants were left attached to the dura or nerve root, and partial resection when a bulky mass was left.

All patients' relative preoperative demographic, clinical, radiographic, operative, histopathological, and perioperative complications and follow-up clinical and radiographic data were reported. All patients formally provided their consent prior to surgery, and the study has been approved by our institutional ethical and research review board.

All patients were submitted for anteroposterior and lateral plain radiographs and T-1 and T-2 weighted MRI of the cervical spine with gadolinium enhancement in the sagittal, coronal, and axial views. Patients with dumbbell schwannomas were further submitted to multi-slice CT scan.

1. Operative Technique

Under general anesthesia, the patient was placed in the lateral decubitus position and the head was slightly flexed and contralaterally tilted and fixed in Mayfield head clamp. The skin incision was marked one finger breadth behind the tip of the mastoid process and extended in a straight fashion according to the target cervical level (Figure 1, 2A). After opening the skin and deep fascia, the wound was deepened bluntly with the index finger between the sternomastoid muscle anteriorly and trapezius muscle posteriorly (Figure 2B). We continued deepening the wound bluntly in the facial plan between the scalene muscles anteriorly and levator scapulae muscle posteriorly targeting the tip of the atlas transverse process above and the lateral mass of the cervical vertebrae below depending on the intended target cervical level (Figure 2C). For C1 and C2 vertebrae after identifying the tip of the transverse process of C1, the inferior oblique muscle was stripped of the tip of the spinous process of C2 and dissected and retracted anteriorly protecting the vertebral artery (Figure 2D). Meanwhile, for C2, C3, and C4 vertebrae, the paraspinal muscles were striped subperiosteally of the lateral masses and the laminae by a Cobb muscle

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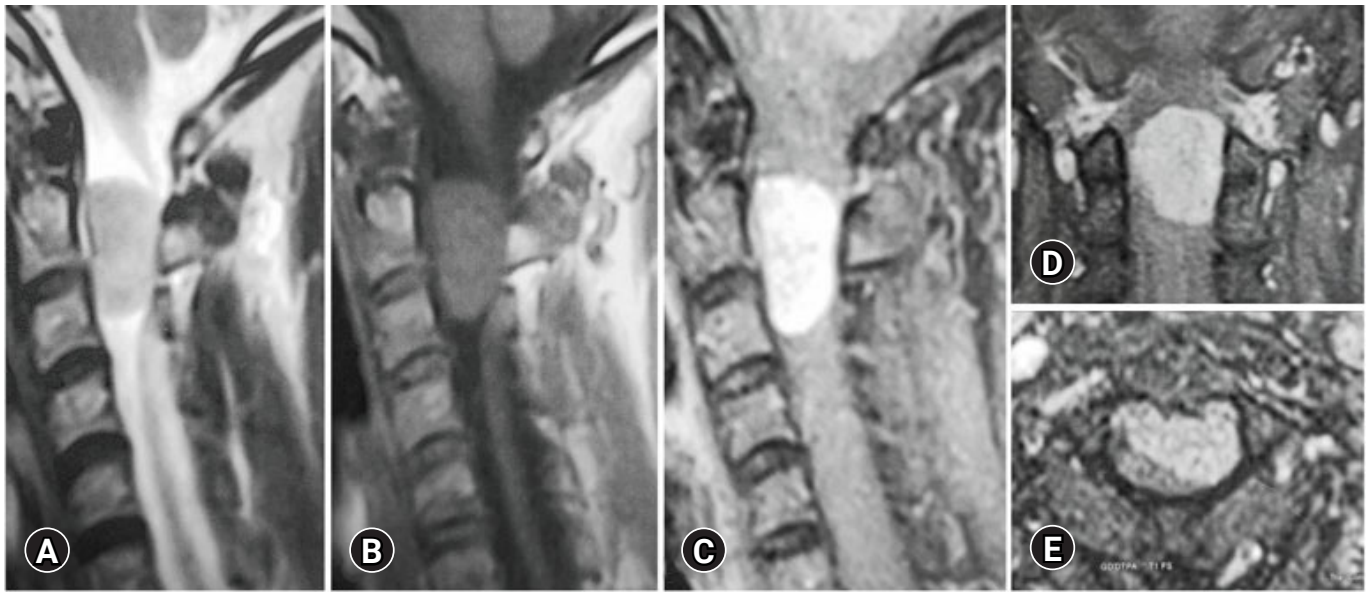

Figure 1. A 52-year-old female patient presented with Brown-Sequard Syndrome. Sagittal T2 (A) and T1(B), and post-contrast T1 MRI sagittal (C), coronal (D), and axial (E) showing large C2-C3 left anterolateral meningioma compressing the spinal cord.

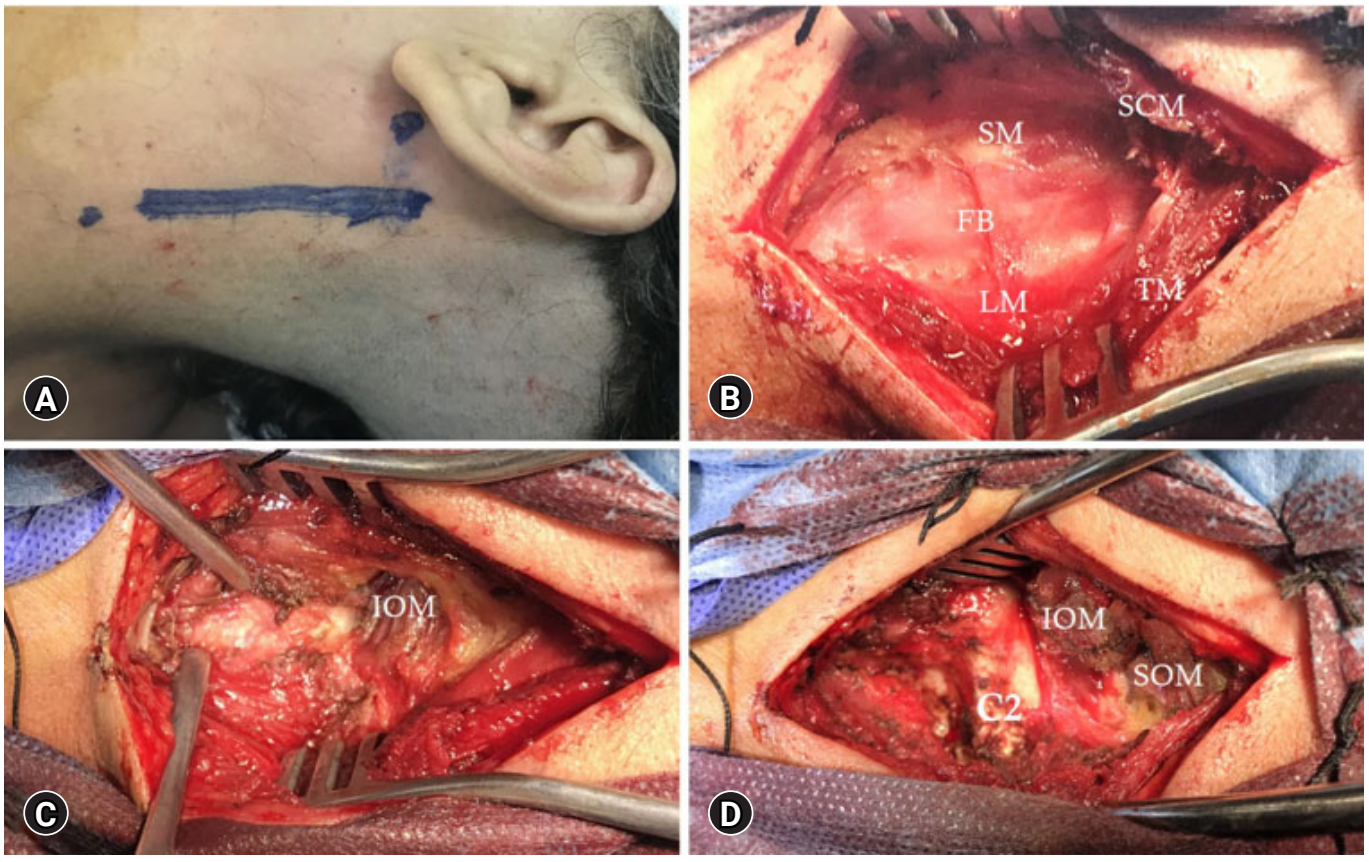

Figure 2. (A) A linear skin incision finger breadth behind the mastoid opposite the index level. (B) Surgical exposure between the sternocleidomastoid (SCM) and trapezius (TM) muscles and then between the scalene muscles (SM) anteriorly and levator scapulae muscle (LM) posteriorly with fat pad (FB) in between that guide us to the deep muscle layer. (C) Exposure of the inferior oblique muscle (IOM) deep to the fat pad. (D) Section of the IOM and superior oblique (SOM) and exposure of C2 lamina.

elevator exposing the laminae between the facet joints and the base of the spinous processes of the corresponding vertebrae (Figure 3A). Working posterior to the facet joint after exposing the hemilaminae of the target level, a laminotomy of these laminae using a high-speed drill and a Kerrison rongeur from the fact joints anteriorly to the base of the corresponding spinous process posteriorly was conducted (Figure 3B). After full dural exposure, a median vertical dural incision was performed, and anterior dural edge was stitched to the ipsilateral muscles to expose the tumor, with the posterior edge remained in situ to protect the spinal cord.

Carrying out this step will directly expose the tumor just beneath the anterior dural edge in the visual access of the surgeon, while the spinal cord is still covered and protected by the posterior part of the dura (Figure 3C). The dentate ligaments could be sharply cut allowing tumor access and relaxing the spinal cord. At this stage, tumor debulking was performed through a combination of thermal bipolar coagulation, rongeurs, curettes, and ultrasonic aspirator (Figure 3D). We usually start dissecting the tumor from the anterior dura, where the tumor originated, using bipolar coagulation. This makes the tumor almost avascular facilitating its removal and/or debulking. Some meningiomas are soft and could be easily sucked through the suction tube apparatus, allowing internal cavitation of the lesion and facilitating tumor mobilization with little cord manipulation. Some are tough, so in these cases we can use ultrasonic aspirator.

In small or medium sized tumors, bipolar coagulation could be utilized to cauterize the plan between the dura and tumors down to the opposite side and hence remove the de-vascularized tumor in one piece. After tumor excision, adequate hemostasis was conducted and the dural base was cleaned and/or cauterized with bipolar coagulation to avoid any tumor recurrence. At this stage, the anterior and contralateral dura is in the direct visual access of the surgeon while the spinal cord is posteriorly covered and protected by the posterior dural sleeve (Figure 4A).

1) In Case of Dumbbell Schwannomas (Figure 5)

After the usual muscle and bony exposure according to the target level, the extradural intraforaminal part of the lesion will come up directly into the visual access of the surgeons between

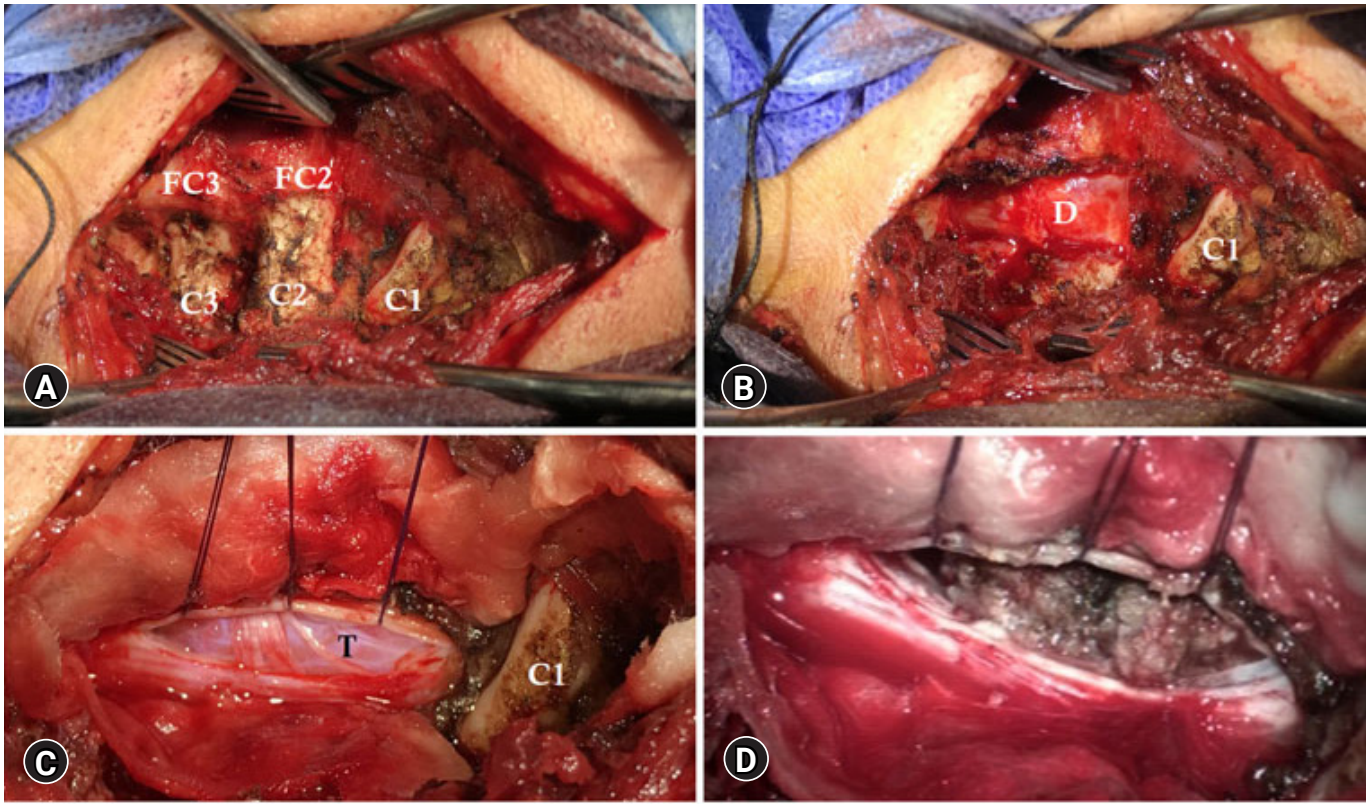

Figure 3. (A) Exposure of C2 lamina and facet (FC2), C3 lamina and facet (FC3), and C1 lamina. (B) C2-C3 laminotomy exposing the spinal dura (D). (C) Opening the spinal dura and tenting the anterior dural edge exposing the meningioma (T) crossed by sensory rootlets. (D) Progressive tumor resection.

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the thinned-out bones of the adjacent vertebrae (Figure 6A). Hemilaminectomy of the adjacent vertebrae was conducted for more exposure of the dural sleeve of the foraminal component as well as the dura of the spinal cord (Figure 6B). The dura covering the intraforaminal part was opened, and excision of that part was performed first. After complete excision of the foram-

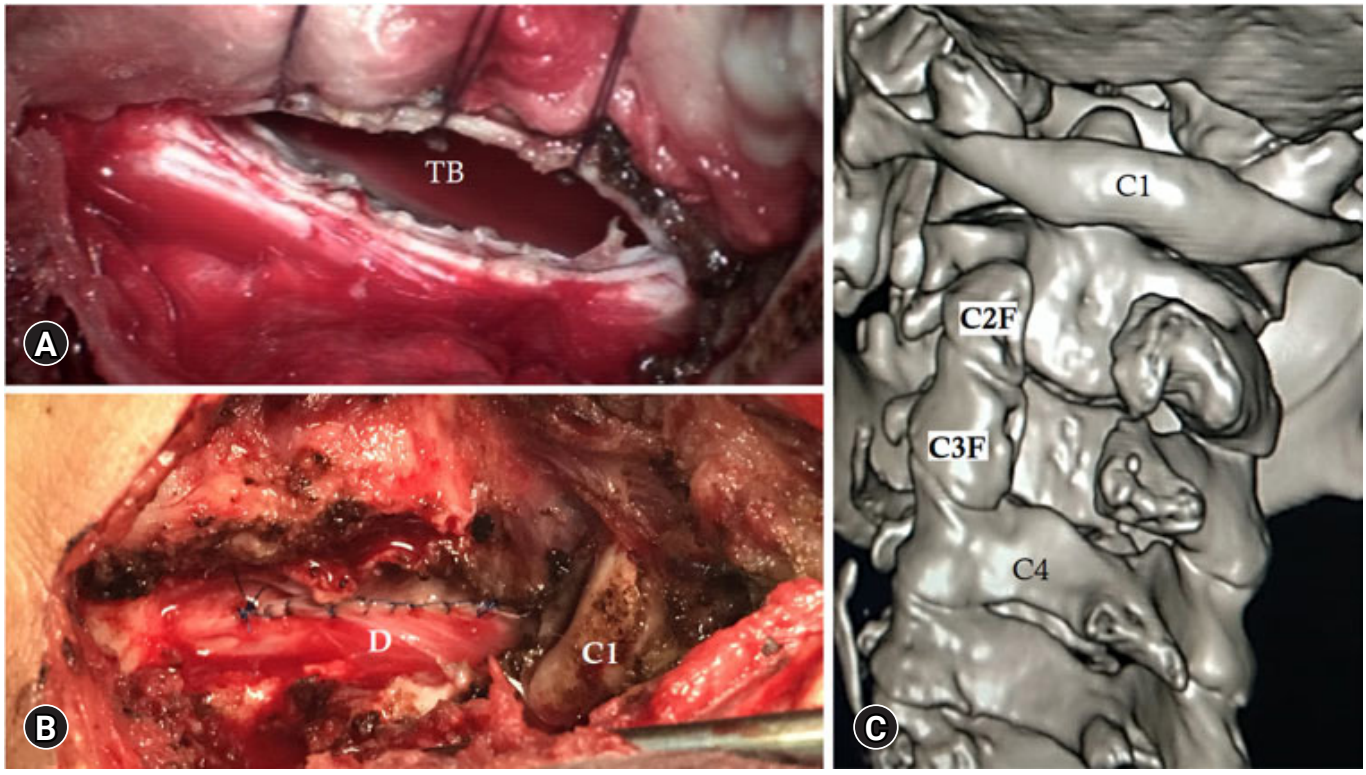

Figure 4. (A) Tumor bed (TB) is shown with the contralateral spinal dura. (B) The dura was sutured directly. (C) 3D CT scan showing the extent of bone removed during the approach.

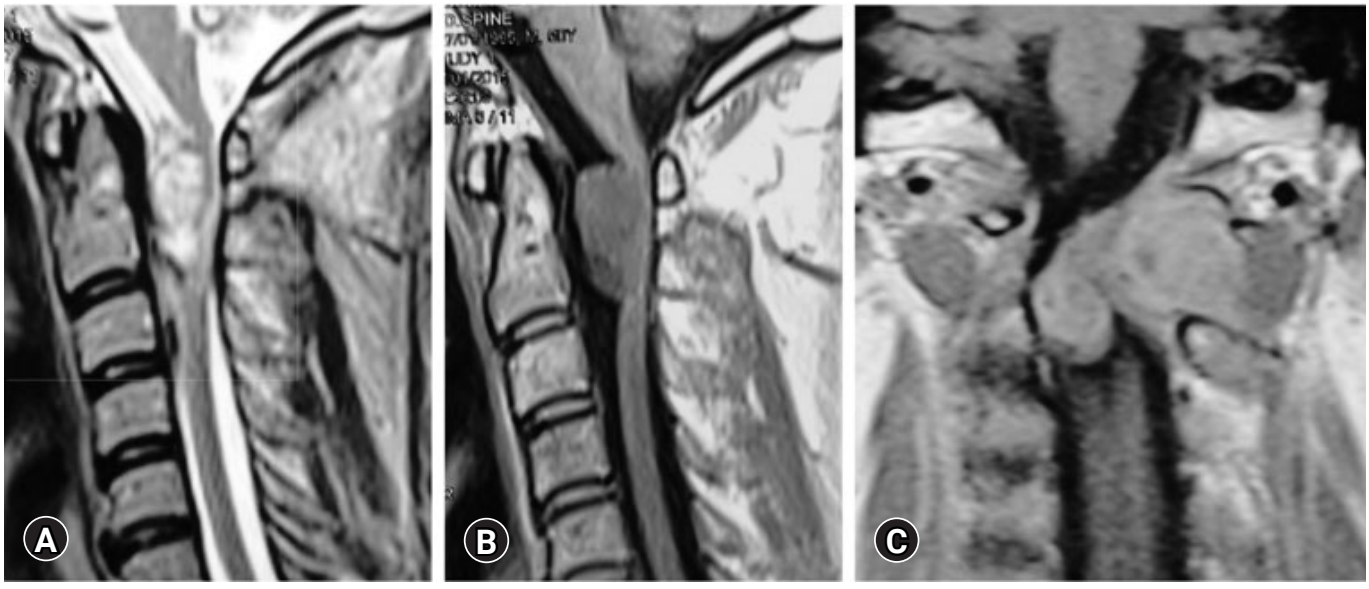

Figure 5. A 44-year-old male patient presented with left occipital pain and gait disturbance. Sagittal T2 (A) and T1 (B), and post-contrast coronal T1 (C) MRI showing large C1-C2 dumbbell schwannoma with large intraformational component compressing the cervical spinal cord.

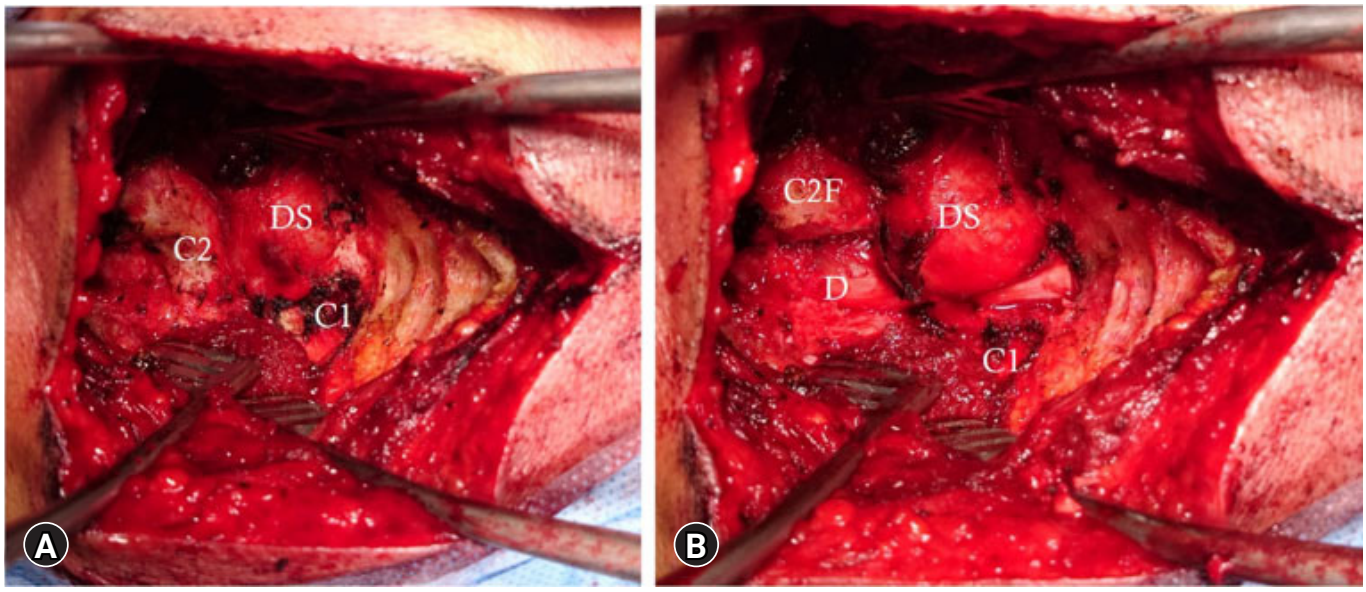

Figure 6. (A) Bony exposure showing the intraformational part of the schwannoma (DS) between the thinned out C1 and C2 laminae. (B) After C1-C2 laminotomy showing C2 facet (C2F), remains of atlas lamina (C1), and the intraforaminal dumbbell schwannoma (DS) compressing the spinal cord dura (D).

inal part, the proper spinal dura was opened either in normal vertical linear fashion or in transverse fashion as an extension of the foraminal dural opening (Figure 7A). After exposing the intradural part, we check the mass mobility and locate the rootlets from which the lesion originates and try to preserve or sacrifice it according to the circumstances (Figure 7B). Neurophysiological monitoring can ensure safety of tumor removal and protect against operative neurologic deficits especially in large sized tumors.

2) Wound Closure and Postoperative Care

A watertight dural closure was then ensured while dural patch could be utilized in some cases (Figure 4B). The wound was closed in multilayer watertight fashion to obliterate any dead space starting with suturing the deep muscles of the posterior triangle. The scalene muscles and levator scapulae muscle are sutured, followed by suture approximation of the sternomastoid and trapezius muscles and then watertight sutures of the aponeurosis, and finally the subcutaneous tissue and skin are sutured. An epidural closed suction drain was inserted with its tube passing through the paraspinal muscle and not through wound to allow watertight closure of the fascia. The drain was observed and if no CSF leak was seen, it was removed 24 to 48 hours postoperatively. If CSF continued to leak through the drain, it was removed, and wound was observed and if a wound bulge appears, a lumbar CSF drainage through a lumbar puncture could be used. An MRI with Gadolinium enhancement was requested for the patient to document complete tumor removal and spinal cord signal and decompression. Patient was discharged from the hospital and scheduled for outpatient's clinic.

2. Statistical Analysis

The Statistical Analysis was performed using IBM SPSS version 25 soft wear (IBM Corp., Armonk, NY, USA). All continuous data are presented as a mean and standard deviation and were tested for normal distribution using the Kolmogorov– Smirnov test. Difference in baseline data and radiologic parameters were analyzed using the t-test or the Mann–Whitney U-test for continuous variables and the chi-square test or Fisher's exact test for the categorical variables. Statistical significance was set at $p<0.05$.

RESULTS

The mean age of our 19 patients was 56.7±17.6 years (range, 39–60 years), including 12 females and 7 males. The major symptoms included gait disturbance in nine, radiculopathy in seven, and urinary symptoms in three with mean duration of symptoms 12.8±12.3 months (range, 3–18 months) (Table 1). At presentation, the 17-point Japanese Orthopedic Association scale (JOA scale) [14] indicated that ten patients were grade 0, five were grade-I, four were grade-II, and none were grade-III.

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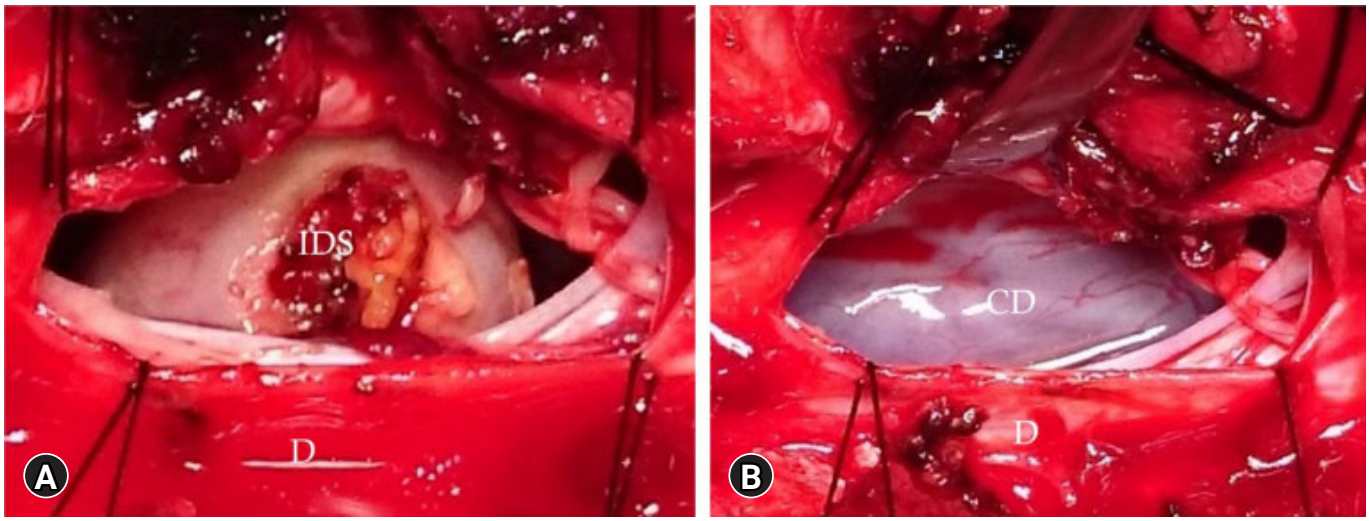

Figure 7. (A) After removal of the intraforaminal part and opening the spinal dura (D) exposing the intradural dumbbell schwannoma (IDS). (B) Tumor removed showing the contralateral spinal dura (CD).

Comorbidity included five hypertensive patients, four diabetic patients, and one rheumatoid arthritis patient.

Overall, nine patients have anterolateral meningiomas, five anterior meningiomas, and five dumbbell schwannomas. Considering the tumor level, the tumor localization is shown in Figure 8. All reported lesions were considered as large tumor as they occupied >50% of the spinal canal on axial MRI. Thirteen patients conducted their surgery from the left side and six from the right side depending on the lateralization of the lesion (Table 2).

All patients in this series underwent their surgical procedures uneventfully without any postoperative neurological deterioration. The summary of perioperative parameters, including operative time, operative blood loss, and hospital stay is shown in Table 2. The mean follow-up period was 29.72±19.80 months (12–52 months). GTR of tumors was reported in 17 patients (89.5%), and STR was reported in two patients out of 19 patients. STR patients included one with large dumbbell schwannoma, where a small part of the intraforaminal component could not be removed, and one with anterior meningioma, where a small part that was tethered to the anterior surface of the spinal cord and could not be removed. Both patients showed no regrowth during the period of follow-up. A patch dural graft was utilized for closing the dura in one schwannoma patient. Histopathological examination of the excised specimens revealed that eight specimens (57.1%) were psammomatous meningiomas, four (28.6%) were fibroblastic meningiomas, and two (14.3%) were meningothelial meningiomas. All excised meningiomas were WHO grade-I.

Reported postoperative JOA scores at 6 months and at the last follow-up showed that all patients improved at least one grade on JOA scores (Figure 9). There was no reported perioperative mortality in this series, while reported morbidity included CSF leak into the suction drain in three patients and superficial wound infection in another one. In patients with CSF leak into the suction drain, we kept the drain until leak stopped or if it continued for a week, we just removed it at that time, and this maneuver prevented wound CSF leak.

Table 1. Data summary of reported patients (N=19)

Parameter	Result
Age (yr)	56.7 ± 17.6 (39–60)
Sex	
Female	12 (63%)
Male	7 (37%)
Duration of symptoms (mo)	12.8 ± 12.3 (3–18)
Symptoms	
Gait disturbance	9 (47.4%)
Radiculopathy	7 (36.8%)
Urinary symptoms	3 (15.8%)
Pathology	
Anterolateral meningiomas	9 (47.4%)
Anterior meningiomas	5 (26.3%)
Dumbbell schwannomas	5 (26.3%)

Numbered are expressed in mean±standard deviation (range).

DISCUSSION

Upper cervical anterolateral and anterior meningiomas and dumbbell or hourglass schwannomas are not uncommon be-

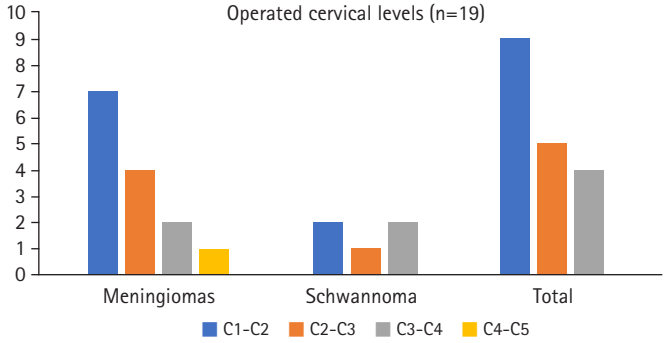

Figure 8. The distribution of patients according to operated cervical levels.

Table 2. Perioperative parameters (N=19)

Parameter	Result
Operative time (min)	139 ± 34 (117–260)
Blood loss (mm)	440.60 ± 170.25 (200–650)
Left approach	13 (68.4%)
Right approach	6 (31.6%)
Gross total resection	17 (89.5%)
Subtotal resection	2 (10.5%)
CSF leak	3 (15.8%)
Superficial wound infection	1 (5.3%)
Hospital stay (d)	4.18 ± 1.89 (2–6)
Follow-up (mo)	29.72 ± 19.80 (12–52)

Numbered are expressed in mean±standard deviation (range).

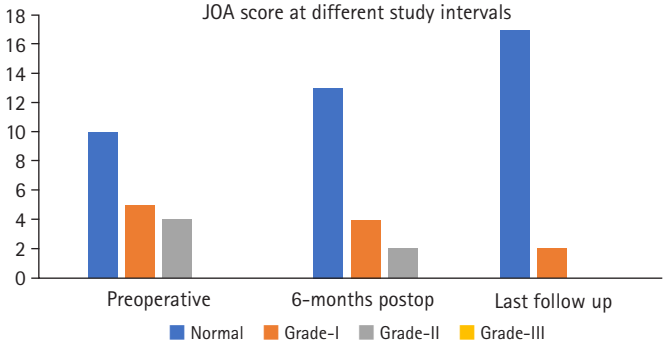

Figure 9. The distribution of patients according to the JOA score at different study intervals.

nign intradural extramedullary tumors. Relative to the dentate ligament, cervical meningiomas are frequently anterolateral, less frequently posterior, and rarely anterior to the dentate ligament and hence to the cervical cord. Overall, 44% of the dumbbell schwannomas are located in the cervical region, and up to 50% of the upper cervical schwannomas are dumbbell [3-5]. Due to the capacious spinal canal, lack of intervertebral foramina, and wide interspace between the atlas and the axis, schwannomas are more frequently huge or dumbbell-shaped than other spine locations [4]. They represent a surgical challenge due to their peculiar anatomical characteristics, extraspinal or anterior location to the spinal cord, and proximity to important vital structures like the vertebral artery and upper cervical spinal cord. Lots of surgical techniques and approaches have been designed to preserve neural function and stability, decrease morbidity, and improve outcome [5-8,10,15,16]. Apart from the standard posterior approach, unilateral hemilaminectomy approach, and anterior or anterolateral approach, the FLA as a minimally invasive technique is one of the attractive approaches designed to overcome all other approaches' shortcomings.

In this case series and technical report, we demonstrated our technique and reported our experience of the FLA in managing upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas. Twelve females and 7 males with a mean age 56.7 years with anterolateral meningioma in 9, anterior meningioma in 5, and dumbbell schwannomas in 5 patients were reported. All patients underwent the procedures without neurological deterioration, mortality, or significant morbidity.

In agreement with our results, Aboul-Enein et al. [13] reported 16 cases of ventrally located cervical meningiomas operated on via the FLA with GTR in 15 patients, no significant morbidity, and recurrence in 3 cases. They highlighted the advantages of their technique in preserving neural function and spinal stability. Wang et al. [8] reported 10 males and 8 females with a mean age 48.2 years who underwent FLA for C1-C2 dumbbell schwannomas with outcome similar to ours. They reported GTR in 15 and STR in 3, with one death due to pulmonary embolism and one recurrence in the 4-year follow-up. They reported that the FLA provided adequate exposure and access with minimal neural manipulation and considered the preferred approach for resection of ventrally or ventrolaterally located tumors.

Lot and George [9] reported 12 C1-C2 dumbbell neuroma cases who underwent posterolateral approach with GTR and reported good neurological results in most patients while preserving stability. Gu et al. [16] were able to perform GTR in 28 out of 35 dumbbell schwannomas through the posterior approach with unilateral facetectomy without affecting the stability. They resected the extradural component first as we preferred in our study. Their results were suboptimal in comparison with ours or other far lateral series [8,9]. McCormick [17] operated upon 12 patients with dumbbell cervical tumor including 9 schwannomas through the posterior approach with

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unilateral facetectomy and highlighted the issues of stability and root section. They concluded that the root section resulted in a nonsignificant deficit although it should be preserved, and unilateral facetectomy did not affect stability although it should be preserved.

Kim and Chung [18] reported 6 large ventrally located cervical schwannomas and 2 meningiomas via the posterior approach with GTR in all and without morbidity. Despite the satisfactory clinical outcome, they highlighted the drawbacks of the posterior approach. The facet joint is preserved to maintain spinal stability, and this limits the surgical exposure requiring a very meticulous microsurgical technique to manipulate vulnerable neural structures. Extraspinal tumor extension, meningiomas en plaque and tumors that tend to adhere to the spinal cord such as psammomatous meningiomas, calcified meningiomas, and recurrent tumors are major limitations of the posterior approach and make GTR sometimes impossible [19,20]. In this case series, 57% of meningiomas were psammomatous, which tend to adhere to adjacent neural structures. However, with the FLA technique, we could easily create a smooth plan of cleavage between tumor and spinal cord, and we achieved GTR in all but one. This highlights the importance of improved visual and surgical access of the FLA in such lesions. We did not encounter a calcified, recurrent, or en plaque one in our series.

Technical Issues

The main advantages of the FLA as a minimally invasive technique are improved visual access to the area ventral to the spinal cord without neural retraction, the feasibility of accessing extradural extension, a safe and better manipulation of the plan between tumor and spinal cord, not destabilizing the spine by preserving the ipsilateral facet joint while the contralateral facets and posterior and anterior elements are untouched, not requiring spinal fixation, and not necessitating vertebral artery manipulation as the lesions are intradural [1,7,11,21]. This is in contrast to the extreme lateral approach where the condyles are violated and vertebral artery is manipulated in most variants of the approach except the retrocondylar variant [12,22].

In their trial to increase the advantages and decrease shortcomings of the standard posterior approach in managing the anterolaterally located meningiomas and schwannomas, some authors [23,24] have introduced some technical modifications in order to improve the surgical access to the tumor. Chang [23] presented a posterior paramedian approach as a simple versatile technique for obtaining lateral viewing angle to the cervical spine. Joaquim et al. [24] presented a modified technique that comprises tenting of the dentate ligament and rotation of the spinal cord in order to increase the small field and allow cord retraction of natural component. Slin'ko and Al-Qashqish [25], in their large series of ventral and ventrolateral tumor operated on using different techniques, reported that since the introduction of the anterolateral and dorsolateral approach, all patients had a safe GTR of their lesion with excellent recovery in most cases.

Lonjon et al. [1] highlighted the importance of FLA in resecting ventral tumors especially hard one while suggesting that the dorsolateral approach may be enough in soft suckable ventral tumors. However, it is still difficult to precisely determine tumor consistency and vascularity despite recent MRI study contribution in this issue such as fluid-attenuated inversion recovery (FLAIR), magnetic resonance elastography (MRE) [26,27], and arterial spin-labeling MRI [28].

The well-known skin incisions for the FLA are the inverted hockey stick incision [29], C-shaped incision [12], and linear paramedian incision [1,7,30]. In addition to the argument that the linear vertical incision decreases the risk of CSF leak, it reduces muscle trauma, provides excellent retraction in the transverse access, creates deep surgical field, and reduces risk of skin necrosis, pseudomeningocele, and fluid collection [31].

Although endovascular embolization may be associated with spinal cord swelling or ischemia, and venous bleeding, it could reduce intraoperative tumor hemorrhage that obscures vision and may preclude GTR was advocated in complex meningiomas [1]. We did not use embolization, and our operative blood loss was not significant and GTR was achieved in 89.5%. Hence, we believe that preoperative embolization is not mandatory in these lesions.

During our follow-up in this series, we have no tumor recurrence or regrowth on the two STR patients. This might be due to our high rate of GTR. According to Komotar et al. [22], tumor recurrence highly depends on the extent of tumor removal. However, most common causes for STR in FLA were never related to lack of exposure but rather adherence to surrounding structures, size of tumor, and prior radiation therapy or surgery [7,22].

This retrospective study has some limitations related to its retrospective nature and relative rarity of reported pathologies and surgical technique. The relatively small number of study populations and short follow-up period are other limitations. In such a situation, a multicenter study is highly recommended.

CONCLUSION

Our results advocate the use of the far-lateral cervical approach as a minimally invasive technique in the resection of the upper cervical anterolateral and anterior meningiomas and dumbbell schwannomas as a safe and effective technique.

NOTES

Ethical statements

This study has been approved by our institutional ethical and research review board of Suez Canal University Hospital (IRB No. 4616#).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Use of Minimally Invasive Spine Surgery in the Management of High-grade Thoracolumbar Spine Injuries

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Objective: Spinal fractures often have devastating sequelae. Thoracolumbar fractures are classified using the Thoracolumbar Injury Classification and Severity score (TLICS) to determine the severity of injury and to guide treatment. Recently advancements in minimally invasive spine surgery (MISS) have led to new approaches to high-severity fractures. Studies have suggested that MISS may yield similar outcomes to conventional, more invasive procedures while producing several benefits.

Methods: This retrospective study involves 46 patients treated from 2005 through 2020 for high grade thoracolumbar trauma from T2 to L5 with a minimum follow-up of 6-months treated with MISS techniques using percutaneous instrumentation.

Results: Average TLICS was 7.5. Patient derived outcome measures with average length of follow-up of 602 days included Oswestry Disability Index 28.9, Patient Satisfaction Index 4.2, Short Form-12 Mental Component Score 51.9, and Short Form-12 Physical Component Score 37.7. Average estimated blood loss was 119.2 mL.

Conclusion: The TLICS is a validated tool used to guide surgical intervention in high grade trauma. The utilization of MISS techniques for the treatment and stabilization of thoracolumbar trauma is efficacious and a viable alternative to traditional open approaches.

Key Words: Spinal cord, Minimally invasive surgical procedures, Pedicle screws

INTRODUCTION

Spinal fractures can result in damage to the adjacent spinal cord or neural structures, reduce quality of life, cause chronic pain, and confer an approximate mortality rate twice that of matched controls [1]. Traumatic spinal injuries most commonly affect the thoracolumbar junction (T10-L2). This region endures a great amount of biomechanical stress, serving as the transition point from the more rigid thoracic spine (and its rib attachments) to the more flexible lumbar spine, making it particularly vulnerable [2].

Traumatic thoracolumbar fractures are characterized into compression, burst, flexion-distraction, extension-distraction, and translation injuries. Compression and burst fractures are generally less severe and associated with lower risk of spinal instability. The mechanism of injury for both compression

and burst fractures is excessive axial force that causes vertebral collapse, such as from motor vehicle accidents or a fall from height. Compression fractures affect only the anterior column while burst fractures affect both the anterior and middle columns [2].

While ligamentous disruption may occur in unstable burst fractures, this is more often seen in translation/rotational, flexion-distraction, and extension-distraction fractures. In translation/rotational fractures, injury results from vertebral displacement in the horizontal plane or from rotation. Flexion-distraction fractures happen due to hyperflexion in which the anterior and middle columns collapse from compression, and the posterior column is separated into two fragments from excessive tension (Figure 1). This mechanism of injury commonly involves a patient wearing only a lap belt during a motor vehicle accident; the collision causes sudden deceleration and hyperflexion against the lap belt. Extension-distraction fractures are less common and happen due to hyperextension. The anterior spine is separated into two pieces from excessive tension, while the posterior spine collapses from compression [2].

Thoracolumbar fractures are classified using the thoracolumbar injury classification and severity (TLICS) scale to determine the severity of injury and help guide treatment. It is classified based on three major categories of (1) injury morphology, (2) posterior ligamentous complex (PLC) integrity, and (3) the patient's neurologic status. Points are assigned for each of the three categories and a higher total score indicates a more severe injury [3]. In terms of using the TLICS score to guide treatment, a total score of 0 to 3 suggests success with non-operative management, while a score of 5 or greater warrants operative treatment. A score of 4 falls into an area of ambiguity in which either non-operative or operative treatment may be appropriate [3]. Non-operative treatment includes mobilization with or without supportive braces and casts. Operative procedures include posterior pedicle screw fixation, decompression, and/or fusion, depending on the clinical scenario [2]. In addition, The American Spinal Injury Association (ASIA) impairment scale is often used to evaluate spinal cord injuries and to determine whether they are complete or incomplete. It considers sensory function, motor function with strength testing, reflexes, and level of neurologic injury [4,5].

Recently, there have been advancements in minimally invasive spine surgery (MISS). Studies have suggested that MISS may yield similar outcomes to conventional, more invasive procedures while producing several benefits. Two randomized controlled trials conducted by Dai et al. [6] and Jindal et al. [7] took steps towards a less invasive approach for posterior pedicle screw fixation by forgoing fusion. Their results indicated that posterior pedicle screw fixation without fusion provided benefits of significantly decreased operative time and blood loss without compromising kyphosis angle correction for burst

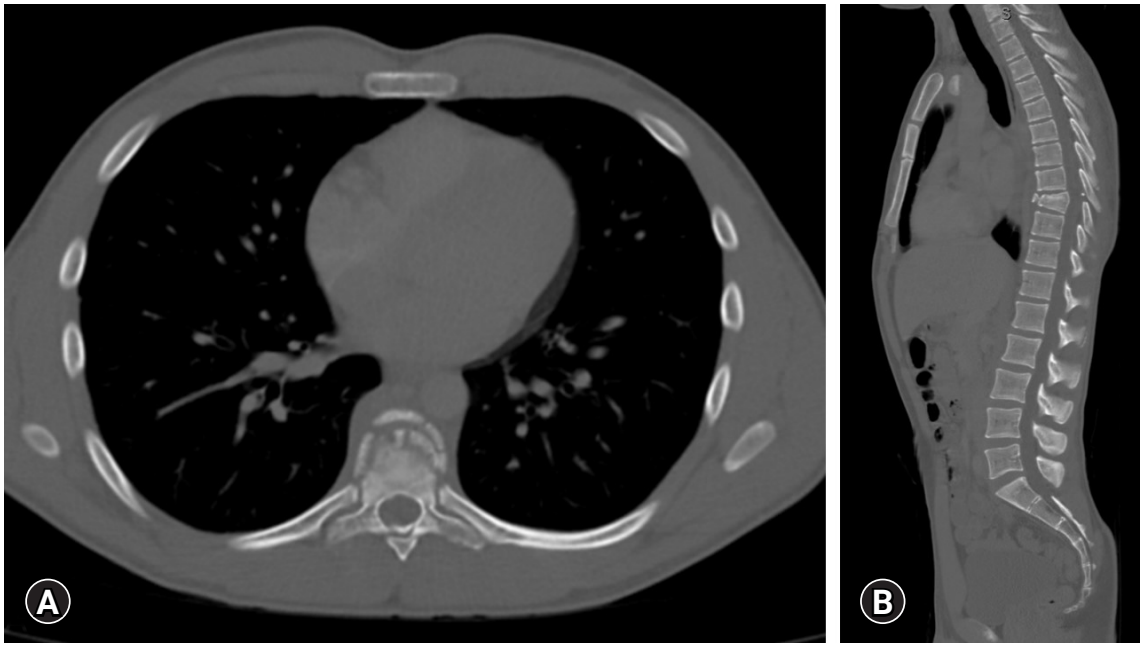

Figure 1. CT images in the (A) coronal and (B) sagittal planes of a thoracic flexion-distraction injury resulting in disruption of posterior column and spinal cord injury.

fractures [6,7]. Furthermore, a prospective, randomized trial by Jiang et al. [8] showed that MISS with percutaneous pedicle stabilization for burst fractures produced no differences in long-term clinical outcomes compared to open paraspinal pedicle stabilization. However, it is important to note that these studies included only low grade fracture cases in which all the patients had burst fractures with load-sharing scores of 6 [6,7], or in which none of the patients had neurologic deficits [8]. Our study investigates the effects of MISS percutaneous approaches for high grade injuries with TLICS scores of 4 or greater.

MATERIALS AND METHODS

The present retrospective case review was approved by the Institutional Review Board (IRB) at our institution (approval #5231). Informed consent was not obtained nor required given the de-identified, retrospective nature of this study. This study involves 46 patients treated by the senior surgeon from 2005 through 2020 for high grade thoracolumbar trauma from T2 to L5 with a minimum follow-up of six month.

Our departmental billing database was used to identify all patients who had undergone posterior MISS for management of acute thoracic, thoracolumbar, or lumbar fractures. Medical records and imaging studies were used to identify cases with the following inclusion criteria: acute traumatic spine injuries; TLICS>4; surgical management with a dorsal minimally invasive surgical technique using percutaneous approaches for all aspects of the procedure including placement of spinal instrumentation, deformity reduction, decompression and/or repair of cerebrospinal fluid leak; and a minimum follow-up period of 6-month.

Medical records were used to identify patient's age, sex, height, weight, body mass index, race, tobacco use, insurance status, and mode of injury.

Pre-operative neurologic status was obtained from the medical records and classified as intact, nerve root injury, cauda equina injury, partial spinal cord injury or complete spinal cord injury. Patients with spinal cord injury were further classified by the ASIA score. Pre-operative imaging studies were used to classify the injury using TLICS. As described, a score of >4 constitutes a high-grade injury suggesting surgical intervention may be indicated. The current study specifically excludes stable burst fractures (TLICS<4). Accordingly, the few patients included with burst fractures had an accompanying neurologic deficit.

Medical records were used to determine the surgical techniques used in terms of decompression, arthrodesis, screw placement, vertebral augmentation, bone graft type and/or repair of cerebrospinal fluid leak.

Patient-derived outcome measures obtained during routine clinical follow-up include the Oswestry Disability Index (ODI), visual analogue scale (VAS) for back and leg pain, SF-12 Physical Component Score (SF-12 PCS), SF-12 Mental Component Score (SF-12 MCS), and a five level patient satisfaction score.

Using the measurements presented by the spine trauma group, pre-operative and final follow-up Cobb angle, vertebral body translation percentage, and anterior vertebral body compression percentage were measured and analyzed for the study population [9]. The Cobb angle was measured between the superior end plate one segments above the injured level to the inferior end plate one segment below the injured level. The vertebral body translation percentage defines the percentage of translation or sheer between the posterior endplates of adjacent segments. The anterior vertebral body compression percentage calculates the amount of wedge deformity in relation in adjacent vertebral bodies above and below the fractured segment.

RESULTS

Baseline patient characteristics are shown in Table 1. This cohort includes 71.1% men and 28.9% women with a mean age of 44.3±21.0 years. The most common modes of injury include motor vehicle collisions, accidental falls, and motor sports injuries. Trauma at the thoracic vertebrae and thoracolumbar junction each accounted for 37.8% of the cases, while trauma at the lumbar vertebrae accounted for the remaining 24.4%.

Average TLICS score was 7.5±1.6. Most injuries were distrac-

Table 1. Patient demographics

Characteristic	Value
Age (yr)	44.4 ± 20.8
Sex	
Males (%)	71.7
Females	28.3
BMI (kg/m^2)	27.8 ± 7.6
Had previous spine surgery (%)	4.3
Tobacco use (%)	19.6
Number of medical conditions	2.0 ± 2.3
Traffic accidents (MVC and motorcycle accidents) (%)	43.5
Accidental falls (%)	34.8
Ski accidents (%)	6.5
Motorsports accidents (%)	4.4
Other (%)	10.9

BMI: body mass index, MVC: motor vehicle collision.

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tion injuries, which comprised 71.1% of cases, and the PLC was injured in 73.9%. With regards to neurological compromise, 19.6%, 4.3%, and 13.0% of cases were classified as ASIA A, B, and C respectively. Overall, neurologic injury was seen in 56.5% of the cases. On the AO classification scale, the majority of cases were B2 (47.8%) and B3 (28.3%). 10.9% of cases were subtype C (Table 2).

Average estimated blood loss was 119.2±126.6 mL, and average length of stay was 12.5±11.2 days. Dural involvement/tear occurred in 10.9% of cases. The average number of segments fused and instrumented were 0.7±0.9 and 3.6±1.5, respectively. The average diameter of the tube used for the MISS procedures was 18.6±1.6 mm (Table 3).

Patient-derived outcomes are shown in Table 4. ODI of the lower back decreased for each of the time points, suggesting decreased levels of disability as time progressed. SF-12 PCS and MCS scores increased for each of the time points and demonstrate improved physical health and mental well-being, respectively. There were also overall decreases in VAS scores indicating pain reduction in the back and lower extremities, as well as increases in work and activity levels. In addition, PSI scores were greater than 4.0 on a scale of 1 to 5 and demonstrated high patient satisfaction with the procedure.

Radiographic data are shown in Table 5. Cobb angle, vertebral body translation percentage, and anterior vertebral body compression percentage were all decreased at latest follow-up compared to pre-operative baselines.

Table 2. Injury classification scales

Variable	Value
TLICS total score	7.5 ± 1.6
TLICS distraction (%)	71.7
TLICS translation/rotation (%)	8.7
TLICS burst injury (%)	19.6
TLICS PLC integrity injured (%)	73.9
TLICS PLC integrity suspected (%)	13.0
TLICS PLC integrity intact (%)	13.0
AO A4 classification (%)	8.7
AO B1 classification (%)	4.4
AO B2 classification (%)	47.8
AO B3 classification (%)	28.3
AO C classification (%)	10.9
ASIA A (%)	19.6
ASIA B (%)	4.3
ASIA C (%)	13.0
ASIA D (%)	0.0
ASIA E (%)	47.8

TLICS: Thoracolumbar Injury Classification and Severity, PLC: posterior ligamentous complex, ASIA: American Spinal Injury Association.

Table 3. Intraoperative data

Variable	Value
Number of segments fused	0.7 ± 0.9
Number of segments instrumented	3.6 ± 1.5
Estimated blood loss (mL)	119.2 ± 126.6
Length of stay/post-operative days	12.5 ± 11.2
Dural involvement/tear (%)	10.9
Tube diameter (mm)	18.6 ± 1.6

Table 4. Patient-derived outcomes

	Timepoint	Average	Number
ODI	Immediate follow-up	39.0 ± 21.6	30
	6-month follow-up	31.8 ± 20.8	37
	1-year follow-up	29.8 ± 18.2	24
	Latest follow-up	28.9 ± 22.3	46
Back VAS	Immediate follow-up	3.3 ± 2.6	30
	6-month follow-up	2.7 ± 2.5	37
	1-year follow-up	2.8 ± 2.4	24
	Latest follow-up	2.6 ± 2.5	46
Right leg VAS	Immediate follow-up	1.9 ± 2.4	30
	6-month follow-up	1.9 ± 2.8	37
	1-year follow-up	1.4 ± 2.1	24
	Latest follow-up	1.5 ± 2.4	46
Left leg VAS	Immediate follow-up	0.9 ± 1.7	30
	6-month follow-up	1.5 ± 2.6	37
	1-year follow-up	1.2 ± 2.5	24
	Latest follow-up	1.2 ± 2.3	46
Work/activity	Immediate follow-up	2.0 ± 1.1	30
	6-month follow-up	2.9 ± 1.3	37
	1-year follow-up	3.3 ± 1.4	24
	Latest follow-up	3.2 ± 1.5	46
PSI	Immediate follow-up	4.1 ± 1.1	30
	6-month follow-up	4.0 ± 1.3	37
	1-year follow-up	4.3 ± 0.8	24
	Latest follow-up	4.2 ± 1.0	46
SF-12 PCS	Immediate follow-up	29.7 ± 8.5	30
	6-month follow-up	33.2 ± 8.5	37
	1-year follow-up	36.5 ± 11.0	24
	Latest follow-up	37.7 ± 11.5	46
SF-12 MCS	Immediate follow-up	47.8 ± 10.4	30
	6-month follow-up	49.6 ± 10.9	37
	1-year follow-up	50.6 ± 9.0	24
	Latest follow-up	51.9 ± 10.0	46

Average length of follow-up in days for the immediate, 6-month, 1-year, and latest follow-up timepoints were 45.9±21.0, 189.0±40.1, 353.3±34.7, and 602.4±442.3 days, respectively.
ODI: Oswestry Disability Index, VAS: visual analogue scale, PSI: Patient Satisfaction Index, SF-12 PCS: Short Form-12 Physical Component Score, SF-12 MCS: Short Form-12 Mental Component Score.

DISCUSSION

In this study, we retrospectively investigated the effects of MISS for high-grade thoracolumbar trauma on patient outcomes. Our patients had an average TLICS score of 7.5±1.6 with an average age of 44.4±20.8 years. Most of our patients were men, and motor vehicle collisions and accidental falls made up 78.3% of cases. Our patient population was therefore similar to that of Wang et al.'s [10] epidemiological study on traumatic spinal fractures.

Average intraoperative blood loss was approximately 120 mL, and average length of stay was less than 2 weeks. Radiographic analysis demonstrated an improvement in translation percentage following MISS reduction and fixation as well as radiographic improvement in both Cobb angles and vertebral body compression percentage without evidence of progressive kyphosis or deformity. A majority of patients underwent unilateral percutaneous instrumentation further minimizing blood loss and surgical time (Figure 2). Individuals requiring long constructs, sacral fixation due to inherent bone quality of the sacrum, those with complete loss of ligamentous integrity in translation injuries underwent bilateral instrumentation (Figure 3). In addition, disability and pain decreased, while activity level, physical health, and mental well-being increased (at the latest follow-up, the average ODI score was 28.9%± 22.3% and the VAS score for back pain was 2.6±2.5). Average SF-12 PCS and MCS scores were 37.7 and 51.9, respectively, at latest follow-up; both SF-12 PCS and MCS scores are approximately 50 for the general population. Therefore, our data indicate that our patients had lower physical capacity but similar mental capacity relative to the general population.

While previous studies of thoracolumbar fractures provided insight on the use of percutaneous pedicle instrumentation for lower grade trauma, our study adds to the literature specifically with regards to MISS approaches for high-grade traumas. Cimatti et al. [11] obtained ODI, SF-36 PCS, and SF-36 MCS scores for patients with AO type A or B fractures who underwent percutaneous pedicle screw fixation, with half their patients receiving an additional lordorizing screw. At 3-years follow-up, their patients had lower ODI scores relative to our patients with a score of 11.68%. Our patient's SF-12 scores can be compared with Cimatti et al.'s SF-36 scores, as previous data has shown

Table 5. Radiographic analysis

Radiographic parameter	Timepoint	Average
CA (°)	Pre-operative	15.4 ± 10.0
	Latest follow-up	13.9 ± 11.1
VBT (%)	Pre-operative	27.0 ± 8.7
	Latest follow-up	10.3 ± 5.9
AVBC (%)	Pre-operative	31.0 ± 17.5
	Latest follow-up	28.0 ± 17.9

CA: Cobb angle, VBT%: vertebral body translation percentage, AVBC%: anterior vertebral body compression percentage.

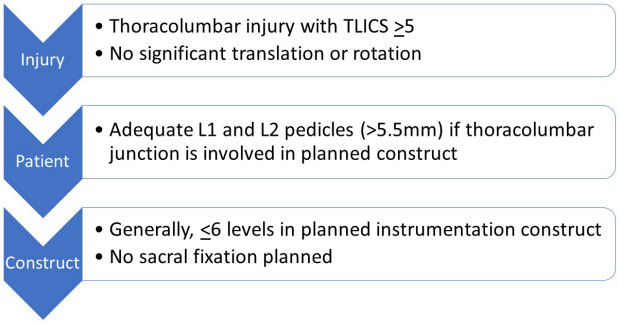

Figure 3. Criteria for use of unilateral thoracolumbar instrumentation in trauma.

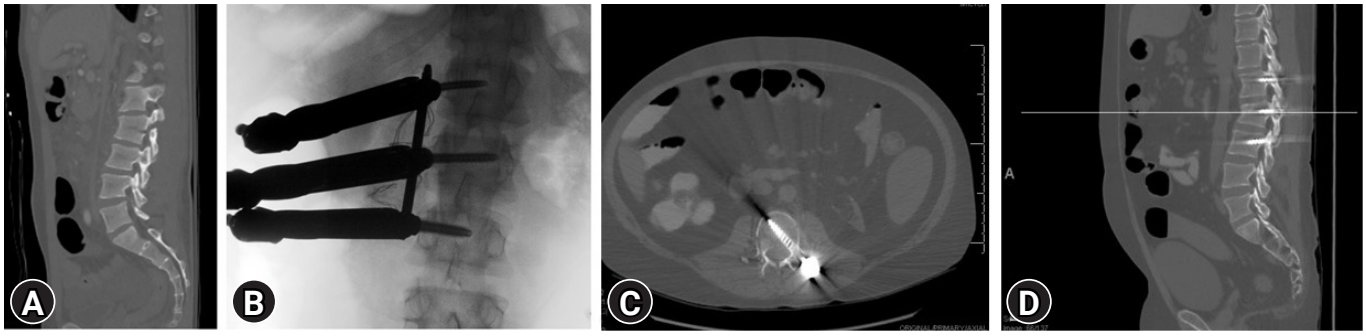

Figure 2. Coronal CT (A) pre-operative CT in the sagittal plane of a L2 flexion-distraction injury, (B) intra-operative AP X-ray with unilateral pedicle screw fixation and percutaneous towers in place, (C) post-operative axial CT with unilateral pedicle screw fixation and (D) post-operative sagittal CT at 3.5 years with healed L2 fracture without evidence of hardware failure or progressive kyphotic deformity.

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the SF-12 to be a valid substitute for SF-36 [12]. Cimatti's et al.'s [11] patients had lower SF-36 PCS and SF-36 MCS scores at 46 and 56, respectively, relative to our patients' SF-12 scores.

Wang et al. [13] investigated lower grade thoracolumbar fractures as well, with most of their cases being classified AO A1-A3. They compared percutaneous to open pedicle screw fixation in 105 patients, with percutaneous screw fixation producing significantly less intraoperative blood loss, shorter recovery times, and lower ODI and VAS scores at 6-month follow-up. In their cohort, percutaneous fixation cases reported a blood loss of 100 mL and average length of stay of 1.5 weeks. Back-pain VAS and ODI scores at 23 month follow-up were 1.4±0.5 and 6.0±1.6%, respectively. Furthermore, Wang et al. [13] showed no significant difference in Cobb angles between the open and percutaneous fixation patients; the angle decreased from 15.8º pre-operatively to 9.5º at 23-month follow-up. The finding that percutaneous pedicle screw fixation decreases intraoperative blood and hospital stay without causing worsened radiographic outcomes for low-grade trauma (predominantly AO type A fractures) was also reported in many other studies, including meta-analyses by Phan et al. [14] and McAnany et al. [15-19].

Our results are comparable to those of other studies that investigated MISS techniques for higher grade thoracolumbar trauma. Zhang et al.'s [20] retrospective study compared the use of a MISS technique with Wiltse's approach and Kambin's triangle to the traditional open posterior technique in 50 patients with high grade upper lumbar fractures. Patients who underwent MISS had an average TLICS score of 6.5, and they experienced significantly less blood loss, length of stay, and 1-year post-operative back pain as reported on VAS. Average blood loss was reported to be 240 mL, average length of stay slightly less than 1 week, and VAS score for back pain at 1-year follow-up was 1.4±0.9 [20]. Regarding percutaneous pedicle screw fixation, Ansar et al. [21] used this technique in 125 patients with high-grade thoracolumbar traumas. Patients selected for the study had either three-column injuries or new neurological deficits on presentation. Average length of stay was 14 days. At a follow-up period of 2 years post-operatively, patients had no pain or mild pain with VAS scores between 0 and 3. Such results correspond with our data of 12.5 days and 2.6 for average length of stay and back pain VAS at 20 month follow-up [21].

Previous studies have demonstrated MISS's efficacy for lower grade thoracolumbar fractures [6-8], including decreased blood loss, shorter incisions, and reduced anesthesia time. Our study indicates that these beneficial effects are applicable for high grade thoracolumbar trauma as well. Limitations to our study include the retrospective design, lack of a comparison group, and heterogeneous patient population which inherently leads to selection bias and therefore may not be generalizable to the population at large.

Our study documents favorable patient and radiographic outcomes with the use of MISS percutaneous instrumentation for high grade thoracolumbar trauma. This cohort is the first to show that for very high-grade thoracolumbar trauma with an average TLICS score as high as 7.5, MISS techniques confer several benefits with regards to radiographic and patient survey outcomes.

NOTES

Ethical statements

This study has been approved by Institutional Review Board of Albany Medical Center, USA (Approval #5231). Informed consent was not obtained nor required given the de-identified, retrospective nature of this study.

Conflicts of interest

No potential conflict of interest relevant to this article.

Authors' contribution

All four authors (MPS, MMS, PE, and JWG) were involved in substantial contributions to the conception or design of the work (including data acquisition and interpretation), drafting the manuscript and revising it, final approval of the manuscript, and agreement for all aspects of the manuscript.

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Clinical Article

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Comparative Study of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Treating Cauda Equina Syndrome

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Objective: The purpose of this study is to evaluate the clinical outcome of cauda equina syndrome (CES) using percutaneous endoscopic lumbar discectomy (PELD) and open lumbar microdiscectomy (OLM).

Methods: Fifteen patients with CES either underwent PELD or OLM from January 2017 to December 2019. The patients were divided into 2 groups according to the surgical methods: the PELD group (with 7 patients, 5 males and 2 females) and the OLM group (with 8 patients, 6 males and 2 females). The clinical outcomes were evaluated by the Visual Analogue Scale score (VAS), motor grade of lower extremities, perineal sensation, anal tone, and bladder dysfunction.

Results: Both groups reported a significant postoperative reduction of VAS score for back and leg pain. When comparing the two groups, there was no significant difference in the improvement of leg pain. However, the improvement in back pain was significantly higher in the PELD group than in the OLM group ($p=0.05$). In the PELD and OLM groups, all 15 patients showed an improvement in preoperative CES symptoms including impaired lower limb motor power, perineal sensations, anal sphincter tone and bladder function at the one-year follow-up. The operation time ($p=0.01$) and length of hospital stay ($p=0.01$) were shorter in the PELD group compared with the OLM group. In the PELD group, the intraoperative bleeding was negligible whereas in the OLM group.

Conclusion: The advantages of PELD, indicate it is a good alterative or option for the treatment of CES patients considering the appropriate indication.

Key Words: Cauda equina syndrome, Percutaneous endoscopic lumbar discectomy, PELD, Lumbar disc herniation

INTRODUCTION

Cauda equina syndrome (CES), which is mainly caused by severe compression of the nerve roots below the conus medullaris, is one of the most serious and complicated spinal pathologies. It is a relatively rare condition most commonly caused by extreme lumbar disc herniation (LDH) and accounts for about 1% to 3% of LDH patients [1,2]. This syndrome causes characteristic symptoms including saddle anesthesia, bowel or bladder dysfunction, sexual dysfunction, severe lower back pain,

unilateral or bilateral sciatica, and motor weakness [1,3]. It is regarded as an emergent condition and it is widely acknowledged that a prompt diagnosis and urgent decompression are critical for better neurological outcomes [4,5].

Traditionally, open lumbar microdiscectomy (OLM) has been widely considered as a standard procedure for CES [6-9]. Surgical techniques of OLM are continually evolving, with a trend toward less aggressive, less invasive procedures to reduce surgical stress on the patient [10-14]. OLM provides additional decompression of nerve roots via laminectomy; however, OLM results in muscle damage, clinically symptomatic scarring of the epidural space, increased risk of postoperative spinal instability, and chronic back pain [15-17]. Moreover, due to the innate nature of the posterior approach, it requires nerve root retraction during discectomy, which increases the risk of neural damage, especially in the case of CES with a huge central disc rupture [18-20].

With the instrumental development of endoscopes and in an attempt to reduce the complication rate, percutaneous endoscopic lumbar discectomy (PELD) has become increasingly popular over the past years. Many studies have shown comparable clinical outcomes of PELD compared with OLM [21-24]. PELD also has several advantages over OLM, including less soft tissue trauma, better bony preservation and rapid recovery [25]. In particular, PELD has the advantage of avoiding root retraction which is evitable in OLM.

On the basis of these advantages, several studies have reported favorable outcomes of CES treated by PELD [26-28]. However, to the best of our knowledge, no study has compared the clinical outcome of CES using PELD and OLM. In this retrospective cohort study, we compared the clinical outcomes when using PELD and OLM to treat CES.

MATERIALS AND METHODS

1. Patient Population

We performed a retrospective cohort study approved by the Institutional Review Board of Daegu Wooridul Spine Hospital (IRB No. 2022-01-WSH-001), and all participants gave informed consent before enrollment. Between January 2017 and Fifteen patients with CES underwent PELD or OLM.December 2019, a total of 15 consecutive patients with CES caused by lumbar central huge disc rupture were treated in Daegu Wooridul Spine Hospital by 4 neurosurgeons. Each surgeon had performed over 300 cases of PELD and over 1,000 cases of OLM throughout their career.

Inclusion criteria were a single level central huge LDH with the following so-called “red flag” symptoms: (1) unilateral or bilateral motor weakness, (2) absent or decreased perineal sensation, (3) absent or decreased or anal sphincter tone, or (4) bladder dysfunction. Exclusion criteria were as follows: (1) LDH concomitant with spinal stenosis, (2) disc herniation with calcified disc, (3) instability, (4) epidural abscess, or (5) neoplasms.

All cases were treated by PELD (with 7 patients, 5 males and 2 females) or OLM (with 8 patients, 6 males and 2 females) within a day of diagnosis of CES and postoperative magnetic resonance imaging was obtained right after the patients were allowed to stand and walk independently.

Medical chart and image databases were analyzed. Patient demographics including age, sex, affected level, body mass index (kg/m^2), duration of symptoms before treatment, and neurological symptoms of CES were reviewed.

2. Surgical Techniques

1) Percutaneous Endoscopic Lumbar Discectomy

A standard transforaminal PELD procedure was performed using the inside-out technique. The procedure was performed under local anesthesia with the patient in the prone position on a radiolucent table and receiving supplemental nasal oxygen. An imaginary line was drawn to the annular puncture site and the skin entry site was marked for the planned surgical trajectory. After infiltration of the entry point (10–12 cm from the midline) with local anesthetics, an 18-gauge spinal needle was introduced into Kambin’s triangle under the fluoroscopic guidance with continuous patient feedback. The final target point of the spinal needle was the medial pedicular line on the anteroposterior view and posterior vertebral line on the lateral view. After inserting the needle in to the disc, discography using indigo carmine was performed to distinguish the pathological fragment clearly during the procedure. After insertion of a guide wire through the spinal needle, the spinal needle was removed and a small skin incision at the entry point was made. A tapered cannulated obturator was inserted along the guide wire and after contacting the annulus, the obturator was inserted into the disc space with hammering until its tip reached the midline on the anteroposterior view. A beveled working cannula was inserted into the disc space along the obturator under fluoroscopic guidance. After removing the obturator, an endoscope (TESSYS System; Joimax, Karlsruhe, Germany) was inserted through the working cannula and positioned at the annular defect site. This was confirmed using axial magnetic

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resonance imaging preoperatively. A targeted fragmentectomy was performed and constant saline irrigation was administered throughout the whole procedure. To remove the trapped disc fragment, the annular defect site was widened using a side-firing holmium: YAG laser (Lumenis Inc., Yokneam, Israel). In cases where the disc fragment was too large to pass through the cannula, it was vaporized by a laser or bipolar radiofrequency coagulator (Ellman International, Hicksville, NY, USA) to reduce the volume and removed with forceps. After removal of the disc fragment and decompression, the beating of the traversing nerve root and dural sac with the pulse of the artery was confirmed. The endpoints of neural decompression were complete visualization of the dural sac and traversing root, dural pulsation, irrigation flutter, and cough impulse. After confirming the relief of preoperative symptoms by asking the patients, the endoscope was withdrawn, and a sterile dressing was applied with a one-point suture (Figure 1).

2) Open Lumbar Microdiscectomy

The patient was placed in a kneeling prone position under general anesthesia. After confirming the target level using fluoroscopy, a 3 cm midline longitudinal skin incision was made, and the paravertebral muscles were dissected and retracted laterally. A Caspar lumbar retractor was applied to obtain a direct view of the operating field and the operative level was confirmed by fluoroscopy. OLM was performed following a bilateral approach. Under microscopic visualization, partial hemilaminectomy, medial facetectomy, and foraminotomy using a high-speed drill were performed. After removal of the ligamentum flavum, the same procedure was performed on the opposite side. The nerve root and thecal sac were retracted gently and the herniated disc fragment was removed with pituitary forceps. Following discectomy, the thecal sac and root were pulsated and retracted without resistance, confirming adequate neural decompression. After meticulous bleeding control, the muscle, subcutaneous tissue and skin were sutured in layer (Figure 2)

3. Statistical Analysis

All statistical analyses were performed using SPSS Version 25 (IBM Corporation, Armonk, NY, USA). Quantitative data were expressed as the mean±SD (standard deviation) or frequency. Each category and difference between two groups were compared using appropriate statistical tools such as the Pearson correlation, Fisher's exact test, the chi-square test, or the Mann-Whitney U-test. A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 15 consecutive hospitalized patients with CES caused by lumbar central huge disc rupture were treated Daegu Wooridul Spine Hospital. Of the 15 patients, 7 underwent PELD and the remaining 8 underwent OLM. On postoperative magnetic resonance imaging, the disc fragment was removed completely in all cases. All patients were followed-up over a year after the procedure in an outpatient clinic and their clinical outcomes were recorded in detail on a medical chart. One patient in each group had a telephone survey because they refused to visit the hospital.

The patients' demographic and clinical characteristics are summarized in Table 1. There were no significant differences in preoperative demographic characteristics between the PELD and OLM groups (p>0.05).

The perioperative outcomes of PELD and OLM for CES are

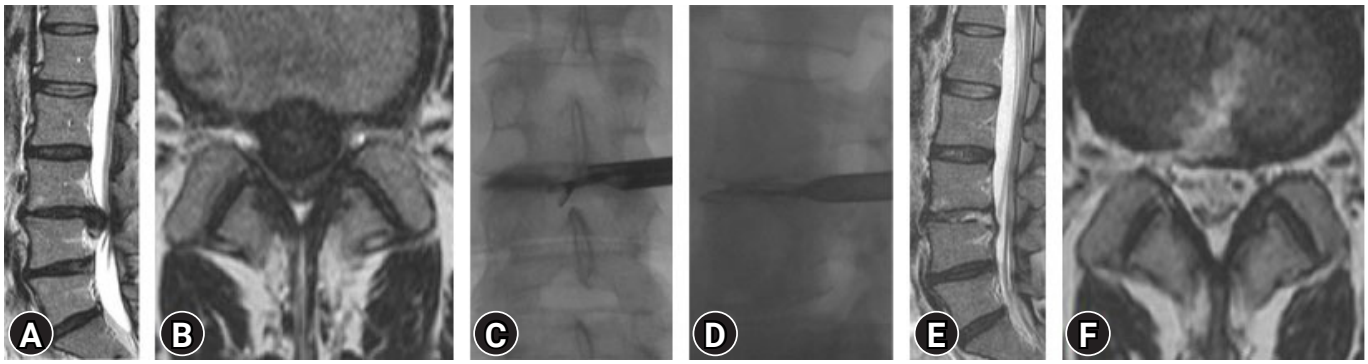

Figure 1. A 37-year-old female patient underwent PELD for disc herniations at the L3-4 level. Preoperative T2 weighted sagittal and axial MRI images (A, B) and intraoperative c-arm images (C, D) demonstrating a huge herniation at the L3-4 level. Postoperative T2 weighted sagittal and axial MRI images (E, F) showed that the herniated disc completely removed.

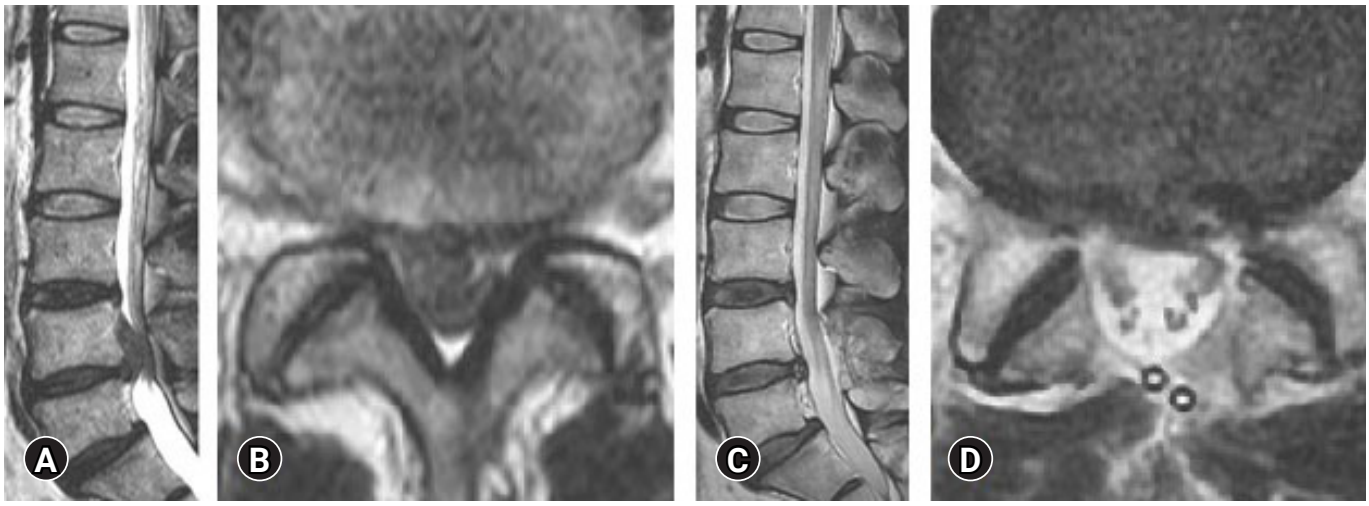

Figure 2. A 45-year-old male patient underwent bilateral OLM for disc herniations at the L4-5 level. Preoperative T2 weighted sagittal and axial MRI images (A, B) demonstrating a up-migrated huge disc at the L4-5 level. Postoperative T2 weighted sagittal and axial MRI images (C, D) showed that the herniated disc completely removed.

Table 1. Preoperative data of PELD and OLM groups

	PELD	OLM	p-value
Number of patients	7	8	-
Age (yr)	34.57±8.848	41.87±15.761	0.524
Gender (M/F)	5/2	6/2	0.876
Level			0.189
L2-3	1	0	
L3-4	2	0	
L4-5	4	7	
L5-S1	0	1	
BMI (kg/m2)	27.94±4.013	27.09±6.210	0.487
Symptom duration (d)	15.29±11.041	17.88±10.816	0.767
Symptom			
Motor weakness	5	6	0.876
Perineal sensation (abscent/decreased)	0/7	0/8	-
Anal tone (abscent/decreased)	0/7	1/7	0.333
Bladder dysfunction	6	6	0.605

summarized in Table 2. Between the two groups, there were no significant differences in preoperative VAS score divided into back and radiating leg pain (p>0.05). Both groups reported a significant postoperative reduction of VAS score for back and leg pain (Figure 3). When comparing the two groups, there was no significant difference in the improvement of leg pain (6.57±0.78 vs. 6.13±0.64, p=0.29; Figure 4A). However, the improvement in back pain was significantly higher in the PELD group than in the OLM group (6.42±1.13 vs. 4.38±0.91, p=0.05; Figure 4B).

In the PELD and OLM groups, all 15 patients showed an improvement in preoperative CES symptoms including impaired lower limb motor power, perineal sensations, anal sphincter tone and bladder function at the one-year follow-up.

The operation time (45.00±4.08 vs. 96.25±10.60, p=0.01) and length of hospital stay (2.43±0.53 vs. 10.63±2.26, p=0.01) were shorter in the PELD group compared with the OLM group. In the PELD group, the intraoperative bleeding was negligible whereas in the OLM group, the estimated bleeding was 235±105 mL.

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Table 2. Perioperative outcomes of PELD and OLM for cauda equina syndrome caused by lumbar disc herniation

	PELD	OLM	p-value
Pre-op VAS			
Back	9.00±0.816	8.50±0.535	0.206
Leg	8.86±0.690	9.00±0.926	0.758
Post-op VAS			
Back	2.57±0.535	4.13±0.641	0.002
Leg	2.29±0.488	2.88±0.835	0.140
Improvement of VAS			
Back	6.42±1.134	4.38±0.916	0.005
Leg	6.57±0.787	6.13±0.641	0.291
Operation time (min)	45.00±4.082	96.25±10.607	0.001
Intraoperative bleeding	Negligible	235.63±105.575	-
Hospital Stay (d)	2.43±0.535	10.63±2.264	0.001

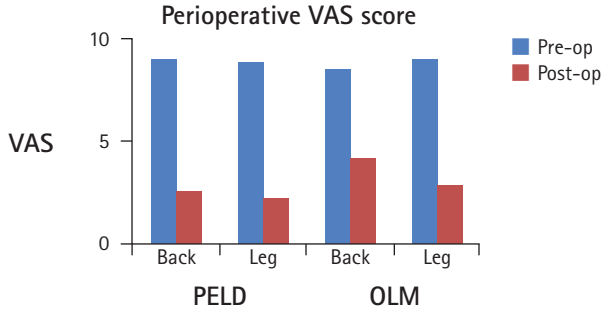

Figure 3. Perioperative VAS score for PELD and OLM.

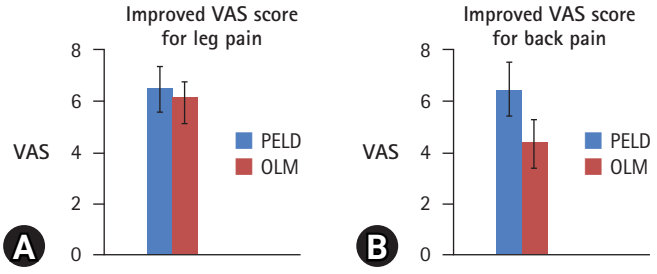

Figure 4. (A) Improved VAS score for leg pain in PELD and OLM. (B) Improved VAS score for back pain in PELD and OLM.

No patients suffered from disc recurrence, postoperative infection, or segmental instability requiring fusion surgery during postoperative follow-up.

DISCUSSION

CES is a very rare condition. That accounts for 1% to 3% of all lumbar disc herniations [29-31]. CES is usually characterized by so-called 'red flag' symptoms including severe low back pain, sciatica (often bilateral but sometimes absent, especially at L5/S1 with inferior sequestration), saddle and/or genital sensory disturbance, and bladder, bowel, and sexual dysfunction.

CES can seriously impair the quality of life without adequate treatment. Busse et al. [32] reported a strong correlation between long CES symptom duration and poor functional outcome. Beyond 24 hours, decompression delay may be associated with a poorer quality of life but, because of the rarity of CES, the sample size in this study was too small to provide definitive conclusions.

Lam et al. [33] showed the long-term prevalence of CES related bladder, bowel, and sexual dysfunction and their impact on the quality of life to inform service provisions. Overall, 71 patients (42 males, 29 females) were enrolled. When post-CES was compared with pre-CES, there was a higher prevalence and significant intrarespondent deterioration of bowel dysfunction, bladder dysfunction, perception of bladder function, sexual function, effect of back pain on sex life and activities of daily living/quality of life ($p<0.0001$ for all). Significant differences in individual questions asked pre-CES versus post-CES were also found.

The aim of our study was to examine differences in clinical outcomes between PELD and OLM. The result of our study showed that there were no significant differences between the two procedures.

PELD has several disadvantages regarding its limited field of view including difficult bleeding control, and because of the working channel, limited instruments can be used during the procedure.

Especially, increased intradiscal pressure resulting from insertion in the working channel, results in nerve root compression.

However, in the case of degenerative disc disease, several studies have reported that the intradiscal pressure was low.

Sato et al. [34] measured the intradiscal pressure (vertical and horizontal) using an advanced pressure sensor in 8 healthy volunteers and 28 patients with ongoing low back pain, sciatica, or both at L4/5. They concluded that the intradiscal pressure in degenerated discs was significantly reduced compared with that of normal discs.

Schnake et al. [35] showed that at the beginning of the degenerative course, the water content of the nucleus pulposus was decreased and the proteoglycane composition was altered. This led to reduction of the intradiscal pressure.

In contrast, performing OLM requires the retraction of the nerve root. In the case of CES, nerve root retraction result in worse neurologic outcomes.

Several studies have reported the advantages of PELD, and

our study confirmed these advantages including less soft tissue trauma, better bony preservation, rapid recovery, and avoiding root retraction.

On the basis of these advantages, several studies have demonstrated the better outcomes of CES treated by PELD [26-28]. Chen et al. [26] studied 11 cases of CES caused by lumbar disc herniation. After emergent surgery with PELD, the lower extremity symptoms were completely recovered or partly decreased. The decreased perianal sensations were partly recovered after surgery, and 9 cases had complete recovery and 2 cases had partial recovery at the one-year follow-up. No patients had anal contraction or bladder problems after the one-year follow-up.

Krishnan et al. [27] reviewed 15 patients who underwent percutaneous transforaminal endoscopic lumbar discectomy (PTELD) under local anesthesia. Ten patients underwent CESI and five patients received CESR. Bladder symptom recovery was 100%, and motor recovery was 80%. The VAS for back pain recovered to 0.53 from 8.00 and the VAS for leg pain recovered to 0.13 from 9.20. The ODI improved to 6.07 from 77.52 and the time to recovery bladder function was 1.47 days. Abnormal PVR urine was normalized in CESR patients at five weeks post-operation.

Li et al. [28] reported the results of 16 CES patients treated by PELD. There was a significant difference in the VAS for leg and back pain between preoperative and 1 day postoperative (p=0.007, p=0.01) as well as between preoperative and last follow-up (p=0.007, p=0.003). Three patients had residual saddle anesthesia remaining at last follow-up; however, these three patients' preoperative radicular pain was relieved. Based on the Macnab criteria, the outcomes were excellent in 7 of 16 patients (43.8%), good in 6 patients (37.5%), and fair in 3 patients (18.7%).

Limitation

Limitation of the study is the retrospective study design and small cohort population. In addition it was not possible to quantitatively evaluate the anal sphincter tone or bladder dysfunction

CONCLUSION

In conclusion, there were no significant differences between PELD and OLM in clinical outcomes for CES. The advantages of PELD (the procedure can be performed under local anesthesia, less soft tissue trauma, better bony preservation, rapid recovery, and avoiding root retraction), indicate it is a good alternative or option for the treatment of CES patients considering the appropriate indication.

NOTES

Ethical statements

A retrospective cohort study approved by the Institutional Review Board of Daegu Wooridul Spine Hospital, and all participants gave informed consent before enrollment (2022-01-WSH-001).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Comparative Study of the Outcomes of Unilateral Biportal Endoscopic Discectomy and Tubular Microdiscectomy Based on the Visual Analogue Scale, Oswestry Disability Index, and Short-form 36

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Objective: Unilateral biportal endoscopic (UBE) discectomy and tubular microdiscectomy (TMD) are widely practiced methods for treatment of lumbar disc herniation. Good clinical outcomes of these methods are reported in many papers, but there are a few comparative studies. This study reports the clinical outcomes of UBE and TMD as minimally invasive surgery methods for lumbar disc herniations and discusses the effectiveness of UBE.

Methods: Sixty-seven patients who had undergone single-level discectomy using one of two methods, UBE or TMD, underwent a prospective follow-up examination. Thirty-four of these patients underwent discectomy using UBE, and the remaining 33 patients underwent TMD. In addition to the traditional measures of outcome, the improvement of generic health-related quality of life and disease-specific measurements like Visual Analogue Scale (VAS) score, Short-form 36 (SF-36), and Oswestry Disability Index (ODI) were evaluated and compared.

Results: Sixty-seven patients with more than 6 months of post-operative follow-up evaluations were included. The mean improvements in the VAS scores for back pain and leg pain and ODI were 2.0, 3.7, and 26.5 for the UBE group and 1.6, 3.0, and 19.4 for the TMD group. The SF-36 physical health component subscale score improved from 35.4 pre-operatively to 54.8 at the last follow-up in the UBE group, and the mental health score improved from 43.5 to 55.1 (TMD group: from 34.9 to 54.3 and 44.2 to 57.1, respectively).

Conclusion: The clinical outcomes of the UBE group are comparable to those of the TMD group. The results indicate that UBE for lumbar disc herniation can be performed safely and effectively as a treatment modality.

Key Words: Endoscopy, Discectomy, Minimally invasive surgery

INTRODUCTION

Lumbar microdiscectomy is a gold standard surgical procedure performed to relieve pain and improve neurological deficit. For decades, several minimally invasive spinal surgical techniques have been developed and they are considered an alternative to conventional open techniques [1]. The use of tubular retractors in conjunction with an operating microscope or endoscope has become popular throughout the world [2]. Through fixed or expandable retractors, physicians could use conventional microsurgical techniques of open surgery. Sever-

al randomized controlled trials have shown that tubular microdiscectomy is safe and effective compared to well-established traditional techniques.

After the concept of endoscopic spinal surgery became more popular, transforaminal percutaneous endoscopic lumbar discectomy (TELD) along with percutaneous endoscopic interlaminar discectomy (PEID) has been widely used for the treatment of lumbar disc herniation [3]. The development of the percutaneous endoscopic technique for lumbar disc disease represents an attempt to improve the operating efficacy, reduce the post-operative pain, limit the length of the patient's hospitalization, reduce perineural fibrosis, and minimize the development of spinal instability [4,5]. However, restricted space and uncomfortable manipulation have limited their effectiveness [6].

Unilateral biportal endoscopy (UBE)-assisted discectomy was recently introduced, and it combines the advantages of endoscopic spinal surgery and conventional spinal surgery. The technique has shown favorable results for treatment of lumbar disc herniation in many previous reports. Most previous studies used perioperative parameters (blood loss, hospital stay, operative time) and qualitative scales (e.g., the modified Macnab criteria and the Odom scale) which are surgeon-based outcomes. They showed good-to-excellent clinical outcomes relevant to improvement in disease-related symptoms after UBE discectomy. However, it is also important to measure patient view of their health-related quality of life, like SF-36. The disease specific measurement like ODI would be also helpful to evaluate the effectiveness of the procedure. To knowledge of authors no prospective study that compared the effectiveness of tubular microdiscectomy and unilateral biportal endoscopic discectomy using all the parameters above has been previously conducted.

In this study, the clinical outcomes of UBE discectomy are compared with those of microscopic discectomy using a tubular retractor; VAS, ODI, SF-36, and perioperative parameters were collected prospectively.

MATERIALS AND METHODS

1. Patient Population

This study was approved by Institutional Review Board of Daegu Catholic University Medical Center (IRB No. CR-22-065). This is a prospective clinical study that involves 67 patients who had undergone single-level discectomy in our department. The patients were divided into two groups by surgical method: 33 patients underwent tubular microdiscectomy (TMD) (Group I), and 34 patients underwent UBE-assisted discectomy (Group II). The inclusion criteria were (1) general symptoms of lumbar radiculopathy, (2) no improvement after conservative treatment for 6–8 weeks, (3) single-level pathologic lesion with no previous back surgery at the same level, (4) no segmental instability in the dynamic flexion-extension radiographs, and (5) documented pre- and post-operative evaluation for at least 6 months. Patients who had a severe neurologic deficit or spinal instability that required fusion and other pathologic conditions, such as fractures, tumors, or infections, were excluded from this study (Table 1).

2. Clinical Evaluation and Follow-up

Patient data on back pain, radiating pain, motor deficit, sensory deficit, reflex deficit, and bowel/bladder dysfunction pre-operatively and at the post-operative office visits were analyzed prospectively. Follow-up examinations were conducted 6 weeks, 3 months, 6 months, 12 months, and then annually after the operation. In addition to a general examination, other information was obtained using the following parameters: VAS scores for back pain and leg pain, ODI for condition-specific measurement, and Short-form 36 (SF-36) for the quality of life, mean blood loss, mean operative time, and length of hospital stay time. All surgeries were performed by 1 surgeon, to eliminate the risk of minor variations in clinical outcomes due to the surgeon's technique and expertise. The result of last follow-up had been analyzed. If a patient was not followed up at the authors' institution, he or she reported the results to the authors post-operatively via a mail survey.

3. Statistical Analysis

Statistical analysis was performed with SPSS version 25.0. A paired sample t-test was used to compare the differences between the pre- and post-operative parameters of the clinical outcomes for each group. The independent two-sample t-test and chi-square test were used to compare the differences between the clinical results of the two groups. A p-value less than 0.05 was considered statistically significant.

4. Surgical Techniques

In the TMD group, all procedures were performed under general anesthesia in the prone position on a radiolucent table. After creating a 2.5 cm skin incision, the paravertebral muscles

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Table 1. Demographic data

Total patient	TMD (n = 33)	UBE (n = 34)	p-value
Age (yr)	57.6 ± 15.3 (range, 15–77)	54.9 ± 15.5 (range, 23–80)	0.467
Male:female ratio	20:13	19:15	0.695
Mean f/u (mo)	20.1 ± 12.0 (range, 6–48)	9.3 ± 5.0 (range, 6–33)	0.000
Mean duration of radiculopathy (mo)	4.7 ± 7.0 (range, 2 wk–36 mo)	3.6 ± 3.5 (range, 1 wk–60 mo)	0.420
Symptoms			
Back pain	16 (48%)	25 (74%)	0.063
Radiating pain	33 (100%)	34 (100%)	
Motor deficit	29 (88%)	33 (97%)	0.153
Sensory deficit	23 (70%)	20 (59%)	0.353
Bowel/bladder dysfunction	2 (6%)	0 (0%)	0.072
Level			
L1–2	1	0	
L2–3	5	2	
L3–4	5	5	
L4–5	13	20	
L5–S1	9	7	

were dissected using a serial dilator. The operating field was exposed using a tubular retractor. Under microscopic view, partial hemilaminectomy and targeted fragmentectomy with discectomy were performed with retraction of the nerve root. After thorough decompression of the nerve root and the thecal sac, closure was performed conventionally.

In the UBE group, all procedures were performed under general anesthesia in the prone position on a radiolucent table. The target pathological disc level was identified under fluoroscopic guidance. A waterproof surgical drape was applied after anesthesia was induced. Two skin incisions were made 1–1.5 cm lateral to the midline. Two portals were used: one for continuous irrigation and endoscopic viewing and the other portal for insertion and manipulation of the instruments used in the decompression procedures (Figure 1). The soft tissue was endoscopically cauterized with radiofrequency ablation to create working space. Next, the spinolaminar junction at the target intervertebral site was identified, a partial laminotomy was performed, and parts of the inferior lamina of the upper lumbar spine and superior lamina of the lower lumbar spine were removed using an electric drill. The interlaminar ligament was dissected and removed using a Kerrison punch and radiofrequency probe, followed by dissection and exposure of the annulus of the protruding intervertebral disc. The ruptured fragments were removed, and decompression of the nerve root and pulsation of the dura mater were confirmed. A drain was then inserted, and the surgical incision was closed.

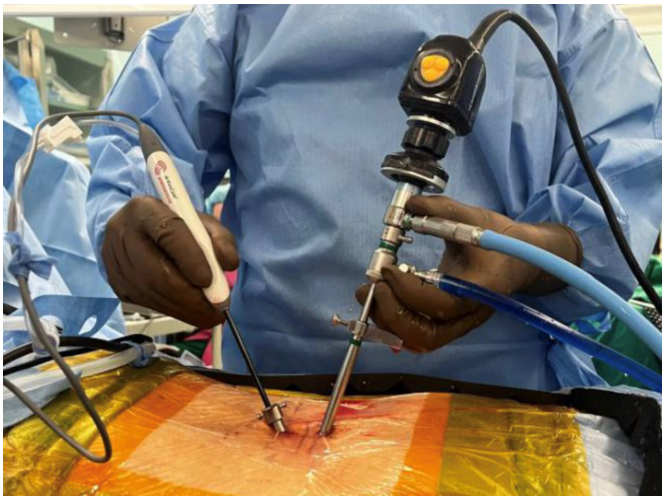

Figure 1. Unilateral biportal endoscopic discectomy.

RESULTS

1. Baseline Characteristics

Data from 67 patients (33 in the TMD group and 34 in the UBE group) were included in the follow-up data, spanning at least 6 months post-operatively. In the TMD group (Group I), there were 20 men and 13 women, and their mean age was 57.6 years (range, 15–77 years). The mean duration of radiculopathy was 4.7 months, and their mean post-operative follow-up period was 20.1 months (range, 6–40 months). Forty-eight percent (16/33) of the patients experienced back pain post-operatively,

100% of patients (33/33) experienced radiating pain; 88% of patients (29/33) experienced motor deficit, 70% of patients (23/33) experienced sensory deficit, and 6% of patients (2/33) experienced bowel/bladder dysfunction (Table 1).

In the UBE group (Group II), 19 men and 15 women underwent UBE-assisted discectomy. Their mean age, duration of radiculopathy, and mean post-operative follow-up duration were 54.9 years (range, 23–80 years), 5.2 months, and 9.3 months (range, 6–33 months), respectively. Clinical symptoms of back pain, radiating pain, motor deficit, and sensory deficit were noted in 75% (25/34), 100% (34/34), 97% (33/34), and 59% (20/34) of patients, respectively. There was no bowel/ bladder dysfunction or reflex deficit pre-operatively. The most common symptom was radiating pain in the leg, and the most affected level was L4-5 in both groups (Table 1).

2. Clinical Outcomes

Measured pre-operatively and at the last post-operative office visit, the mean VAS regarding pain discomfort scores for back pain were 4.12 and 2.48, respectively, in Group I and 4.74 and 2.71 in Group II. The mean improvements in the VAS scores for back pain were statistically significant in both groups (p=0.010 and 0.003), but the differences between the two groups were not significant. The mean pre-operative and post-operative VAS scores for leg pain were 5.67 and 2.64, respectively, in Group I and 6.15 and 2.47 in Group II. The mean improvements in the VAS scores for leg pain were statistically significant in both groups (p<0.001 and p<0.001), but differences between the two groups were not statistically significant. The mean ODI scores recorded pre-operatively and at the last follow-up were 43.33 and 23.9, respectively, in Group I and 49.35 and 22.8 in Group II. The mean improvements in ODI scores were statistically significant in both groups (p<0.001 and p<0.001), but differences between the two groups were not statistically significant. The mean SF-36 physical health component scales recorded pre-operatively and at the last follow-up were 34.9 and 54.3, respectively, in Group I and 35.4 and 54.8 in Group II. The mean improvements in the SF-36 physical health component scales were statistically significant in both groups (p=0.008 and p<0.001), but differences between the two groups were not statistically significant. The mean SF-36 mental health component scales recorded pre-operatively and at the last follow-up were 44.2 and 57.1, respectively, in Group I and 43.5 and 55.1 in Group II. The mean improvements in the SF-36 mental health component scales were statistically significant in both groups (p=0.010 and 0.006), but there were no significant differences between the two groups (Table 2, Figure 2).

The mean blood loss was 80.5 mL in Group I and 49.1 mL in Group II, significantly lower in Group II than in Group I (p<0.001). The mean operative times were 108.8 minutes in Group I and 82.8 minutes in Group II, significantly shorter in Group II than in Group I (p<0.001). The mean hospital stay was significantly shorter in Group II than in Group I (p=0.002) (Table 3).

Complications occurred in 3 patients in Group I and 3 patients in Group II. Recurrence of herniation at the same level and at the ipsilateral side required reoperations in 1 and 2 patients, respectively, over both groups. Dural tear, which occurred in 1 patient in Group I, presented no neurologic deficit and was successfully managed after 48 hours of bed rest.

DISCUSSION

Conventional microdiscectomy remains the gold standard for lumbar intervertebral disc herniation. However, conventional open lumbar microdiscectomy would inevitably disrupt the posterior paraspinal muscles and lead to long-term muscle atrophy and chronic back pain [7,8]. Therefore, minimally invasive spine surgery (MISS) has been developed to avoid them, with the progress of technology.

With the integration of the microscope and tubular system,

Table 2. Clinical outcomes between the TMD group (Group I) and UBE group (Group II)

	Group I			Group II		
	Pre-op	Post-op	p-value	Pre-op	Post-op	p-value
VAS for back pain	4.12	2.48	0.010	4.74	2.71	0.003
VAS for leg pain	5.67	2.64	<0.001	6.15	2.47	<0.001
ODI score	43.3	23.9	<0.001	49.4	22.8	<0.001
SF-36 PHCSS	34.92	54.27	0.008	35.40	54.82	<0.001
SF-36 MHCSS	44.16	57.05	0.010	43.53	55.09	0.006

VAS: Visual Analogue Scale, ODI: Oswestry Disability Index, SF-36: Short-form 36, PHCSS: physical health component subscale score, MHCSS: mental health component subscale score.

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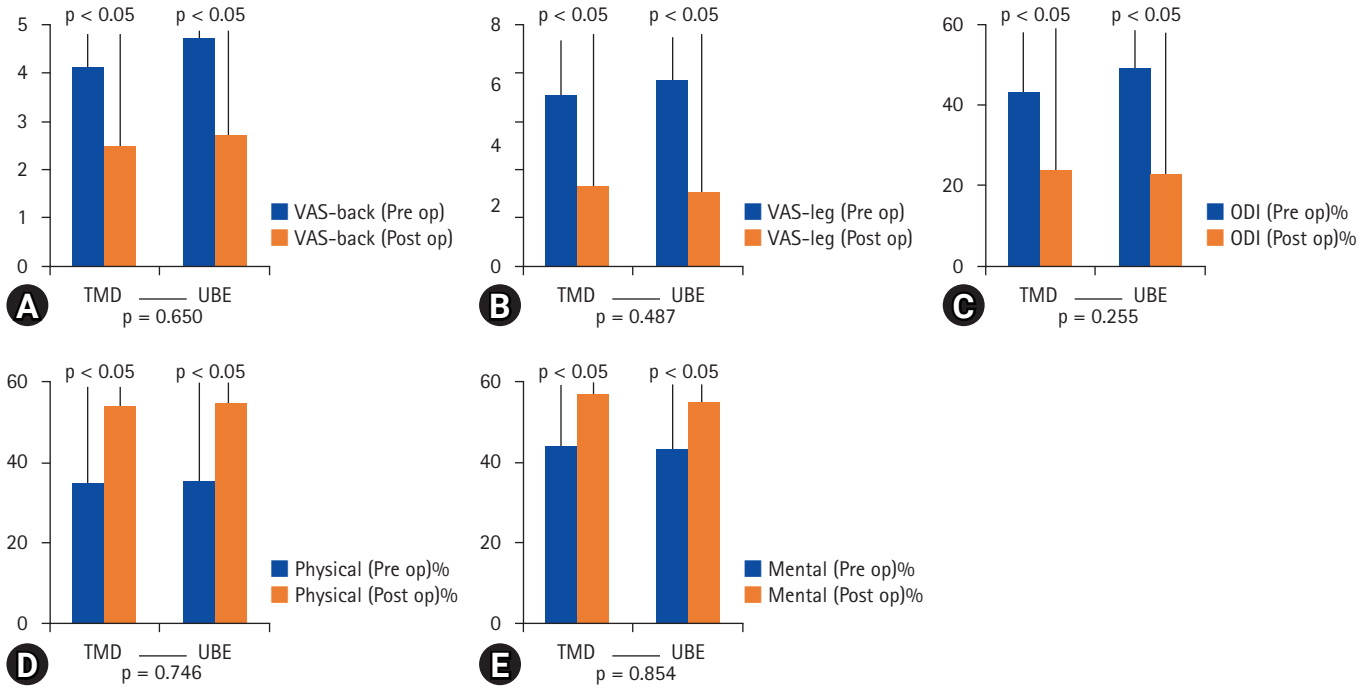

Figure 2. Comparison of clinical outcomes between tubular microdiscectomy and unilateral biportal endoscopic discectomy. (A) Visual Analogue Scale (VAS) score for back pain, (B) VAS score for leg pain, (C) Oswestry Disability Index, (D) Physical health component subscale score, and (E) Mental health component subscale score.

Table 3. Perioperative parameters of the TMD group and UBE group

	TMD	UBE	p-value
Mean blood loss (mL)	80.5 ± 36.0	49.1 ± 18.3	< 0.001
Mean OP time (min)	108.8 ± 25.6	82.8 ± 22.7	< 0.001
Hospital stay (d)	10.4 ± 5.7	6.9 ± 2.4	0.002
Complications			
Superficial infection	0	0	
Temporary N. root injury	0	0	
Recurrence rate (%)	2 (1)	3 (2)	
Durotomy	1	0	
Discitis	0	0	

TMD: Tubular microdiscectomy, UBE: Unilateral biportal endoscopic.

the MISS with tubular retractor gained popularity with minimally invasive spine surgeons, and numerous reports emerged for lumbar microdiscectomy. On the other hand, TELD along with PEID has a less invasive modality, and several advantages over other forms of MIS: it more extensively preserves normal paraspinal structures during surgery, reduces post-operative pain to allow early discharge, and can be performed under local anesthesia [5,9]. However, the uniportal system uses combined channel (viewing and instrumental) that limits the independent movement of instruments. Furthermore, although it can remove soft disc herniation and ruptured disc materials without foraminal obstruction, restricted movements of the instruments and obstructed intervertebral foramen following degenerative changes could disturb the procedure [1,3].

The UBE technique was first described by Soliman [10] as irrigation endoscopic discectomy (IED) in 2013 and by Eum et al. [11] as percutaneous biportal endoscopic decompression (PBED) in 2016 and was reported to be feasible for lumbar spinal surgery, including lumbar fusion, by many authors in the following years [1,12,13]. The advantages of UBE are increased surgical movement of the instruments with independent visualization and working portals, good and wide field of visualization conferring unrestricted access to contralateral and foraminal areas, less bleeding because of continuous irrigation, visual similarity between the surgical field and that of conventional microscopic surgery, and a reduced armamentarium because the UBE system uses separated channel for instruments and only 0° or 30° arthroscopy for the knees or shoulders are used for standard laminectomy.

A systematic review of UBE spinal surgery collected 556 patients and 679 levels from the selected 11 studies in 2019 by Lin et al. [1] They concluded that UBE may be a feasible option for lumbar spinal surgery. However, the existing studies were limited to small cohorts and short-term follow up.

Kim et al. [12] reported a comparative study of clinical out-

comes of single-lumbar discectomy using UBE and open lumbar microdiscectomy (OLM). This study showed superiority in terms of short-term back pain recovery, a small volume of intraoperative blood loss, and less hospital stay. On the other hand, improvements in short-term leg pain and long-term back and leg pain, modification of the quality of life (ODI), patient satisfaction (modified MacNab score), and complication rate were similar to that of OLM. They were satisfied with the result because despite the statistically significant prolonged operation time, patient satisfaction was equivalent to conventional open procedure. That would be due to the tissue- sparing nature of the procedure, rapid pain recovery, short hospital stay, favorable pain outcomes, and improved quality of life.

Aygun and Abdulshafi [14] reported a prospective clinical study comparing UBE and tubular microendoscopy in the management of single-level degenerative lumbar canal stenosis. Their study was conducted to test the feasibility of the UBE technique in management of lumbar canal stenosis using ODI, Zurich Claudication Questionnaire (ZCQ), and Modified MacNab Criteria (MMC). In this study, UBE cases had statistically superior results in ODI and ZCQ scores that represents the superiority of UBE over tubular microendoscopy in management of single degenerative lumbar canal stenosis. They thought that tubular microendoscopy has its limitations attributable to changing the working cannula direction, narrow visualization field, difficulty in bleeding control, and inadequate achievement of contralateral neural decompression. In contrast, UBE provided a clear visualization of neural elements, degenerative surrounding structures, and congested epidural venous plexus, which are crucial for achieving the best operative results.

According to the study above, we expected that UBE-assisted discectomy would have superior results in disease specific measurement and patients HRQOL measurement compared to tubular microdiscectomy. Therefore, this study focused on comparing the clinical outcomes of UBE-assisted discectomy and TMD as pain scales by VAS, disability-related outcome scales by ODI, and health-related quality of life scales by SF-36 [15].

The ODI questionnaire was published in 1980 by Fairbank et al. [16]. This questionnaire is widely used for patients with lumbar spinal pain due to its disease-specific nature and convenience [15]. Various outcome questionnaires have been developed to assess the impact on patient quality of life. The goal of these questionnaires is to measure patients' views of their health and daily activities. Health-related quality of life refers to the effects of a patient's health on his/her overall well-being [17]. The most commonly used generic health-related quality of life survey is the SF-36 [15,18].

FDA standards for good-to-excellent operative outcomes include a 15-point improvement in ODI plus maintenance or improvement in SF-36 score [19]. In our study, significant improvements in VAS scores for back pain and leg pain, ODI, and SF-36 across both physical and mental component subscales were achieved in both UBE and TMD groups. The mean decrease in ODI scores was 19.4 and 26.5 in Group I and II, respectively, at the final follow-up, with improvement of SF-36 score. This result could be interpreted as a significant improvement in the quality of life of the patients in both groups.

However, statistical difference between two procedures was not significant in VAS, ODI, and SF-36. Unlike the previous study of Kim et al. [12], the operative time was even shorter in UBE compared to TMD. There would be several reasons for the result. Firstly, tubular microdiscectomy would be less destructive than conventional discectomy. The paraspinal approach would maintain multifidus tendon attachment to the spinous process and integrity of dorsolumbar fascia and avoid injury to the posterior paraspinal muscles. Also, the tubular retractor is a "non self-retaining" system, which reduces the pressure on the tissues for holding the retractor in place. Furthermore, a tubular retractor maximizes the surface contact area which minimizes the pressure per unit area. Secondly, unlike the report of Aygun et al. [14] which was about decompression surgery, tubular microdiscectomy does not need to change the working direction of tubular retractor and it would result in less damage to posterior paraspinal muscles.

Choi et al. [20] compared the surgical invasiveness of lumbar microdiscectomy and UBE discectomy using differences in creatine phosphokinase (CPK), C-reactive protein (CRP), and MRI before and after surgery. The study showed significantly lower CPK, CRP, and MRI change in the UBE discectomy group, which indicates that there was less muscle injury following UBE discectomy than microdiscectomy, which eventually affects hospital stay duration and post-operative back pain in the early stages. In the present study, perioperative parameters of mean blood loss, mean operation time, and hospital day were significantly superior in the UBE group. The reduction of blood loss and operation time might have led to less tissue injury, resulting in reduction of hospital stay time in the UBE group. Immediate post-operative back pain data were not collected in this study, but the UBE group tended to require a lesser opioid dosage than the TMD group.

The limitations of this study is that it was nonrandomized nature, small size, and variant duration of follow up period due to the transitional period of surgical methods from TMD- to

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UBE-assisted discectomy in the authors' department. However, the results show that UBE is a safe and effective procedure, compared with well-established minimally invasive technique. Adequate randomized prospective studies for UBE are required to verify the present study.

CONCLUSION

The outcomes of UBE-assisted discectomy, including VAS, ODI, and SF-36, are comparable to those of TMD. Meanwhile, the UBE technique has some advantages regarding blood loss, operation time, and hospital stay. Therefore, UBE can be considered an alternative surgical option as an MIS technique.

NOTES

Ethical statements

This study was approved by Institutional Review Board of Daegu Catholic University Medical Center (IRB No. CR-22-065).

Conflicts of interest

No potential conflict of interest relevant to this article.

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A Clinical Pilot Study Showing the Safety and Efficacy of Intramuscular Injection of Atelocollagen for Prevention of Paraspinal Muscle Atrophy after Spine Surgery

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Objective: The objective of this study was to assess the safety and efficacy of intramuscular injection of atelocollagen for the prevention of paraspinal muscle atrophy after spine surgery. Atelcollagen has been widely used as an intradermal filler to restore soft tissue defect. Many studies demonstrated that atelocollagen provides good therapeutic results by promoting cell proliferation and enhances the healing effect on injured connective tissues such as tendons and fasciae, while causing few complications.

Methods: A total of 118 patients who underwent single level of posterior lumbar interbody fusion (PILF) between December 2017 and April 2019 were retrospectively reviewed. In the study group of 60 patients, 3 mL of gel-type 3% atelocollagen solution was prepared and injected into the multifidus muscle during wound closure. Clinical efficacy was evaluated by the improvement of back pain, elevation of a muscle enzyme, and inflammatory markers. Radiologic efficacy was evaluated with a comparison of density and cross-sectional area (CSA) of multifidus and erector spinae muscle in CT images.

Results: Visual analogue scale (VAS) scores for back pain was not significantly lower in the study group postoperatively compared with the control group. The reduction of postoperative paraspinal muscle density and CSA was significantly lower in the study group. The serum level of muscle enzyme and inflammatory markers were significantly lower in the study group. No major procedure-related complications were observed during the follow-up period.

Conclusion: Intramuscular injection of atelocollagen is safe and feasible for the prevention of paraspinal muscle atrophy after spine surgery. This novel method seems advantageous for accelerating wound healing without causing inflammation.

Key Words: Atelocollagen, Multifidus, Paraspinal muscle, Muscle atrophy, Intramuscular injection

INTRODUCTION

Recently spine surgeons have been concerned about the surgical approach-related morbidity resulting from an iatrogenic paraspinal muscle injury in posterior lumbar surgery. Many studies have explained the mechanisms of the injury and reported new techniques to prevent the injury [1-3], but there is still not an effective and established treatment proven yet.

Collagen is a triple helix polymer protein that makes up 30 percent of the body's total protein [4]. Collagen is a structural

and biological component of tissues including cartilage, bone, vessels, skin, and tendon. Collagen fibers act to transmit forces, dissipate energy, and prevent mechanical failure in connective tissues [4,5]. A collagen molecule has an amino acid sequence called a telopeptide at both N- and C-terminals, which confers most of the collagen's antigenicity. If this collagen with telopeptide is injected into the human body, an immune response can occur because of the antigenicity of the telopeptide at N- and C-terminals [6].

Atelocollagen is a material that is extracted from animal skin and is prepared by protease or pepsin treatment to remove this antigenic telopeptide region from both ends of the collagen molecule. Highly purified atelocollagen is low in immunogenicity because it is free from telopeptides and has many advantages for biocompatibility and optimizing collagen-cell interaction for efficacy and lower side effects [7]. Studies using human subjects and experimental animals have shown that atelocollagen provides good therapeutic results by promoting cell proliferation and early epithelialization while causing little rejection and few complications [8].

Over the past decade many reseachers have conducted studies in tissue engineering using collagen to enhance muscle recovery. However, in our knowledge, there is not a single study on prevention of paraspinal muscle injury after spine surgery. Our primary hypothesis was that atelocollagen may affect postoperative muscle recovery by promoting local stem cell and myoblast proliferation without adverse events. The object of this study is to assess the safety and efficacy of intramuscular injection of atelocollagen for the prevention of paraspinal muscle atrophy after spine surgery.

MATERIALS AND METHODS

Approval of the institutional review board for this study was obtained (CMC IRB No. PC22RISI0010). Patients who underwent single level mini-open posterior lumbar interbody fusion (PILF) from December 2017 and April 2019 at Seoul St. Mary's Hospital were identified and retrospectively reviewed. Inclusion criteria for the surgery were degenerative indications requiring a fusion procedure such as segmental instability, spondylolisthesis, and disc degeneration disease with herniation and/or spinal stenosis. Patients with previous spine surgery, spine trauma, infection, ankylosing spondylitis, malignancy, and congenital spinal deformities were excluded from the study. To eradicate the bias about paraspinal muscle quality, patients with diagnosis of sarcopenia were also excluded. The diagnosis of sarcopenia was done using diagnostic criteria proposed by The Asian Working Group for Sarcopenia (AWGS) [9]. All patients were observed clinically and radiologically for a minimum of 12 months. Informed consent from the study pateints were deemed exempt from requirment due to restrospective study design.

All operations were conducted by a single neurosurgeon (J.W.H.) with the same surgical protocol (Figure 1). All patients underwent mini-open PLIF in the prone position on a Jackson table. Following a midline skin incision and bilateral paraspinal muscle dissection, decompressive surgery consisting of total laminectomy, medial facetectomy, and foraminotomy bilaterally was done. The thecal sac was retracted gently to expose a corridor to the disc space. The endplates and disc space were then prepared followed by the insertion of PEEK cages (OIC;

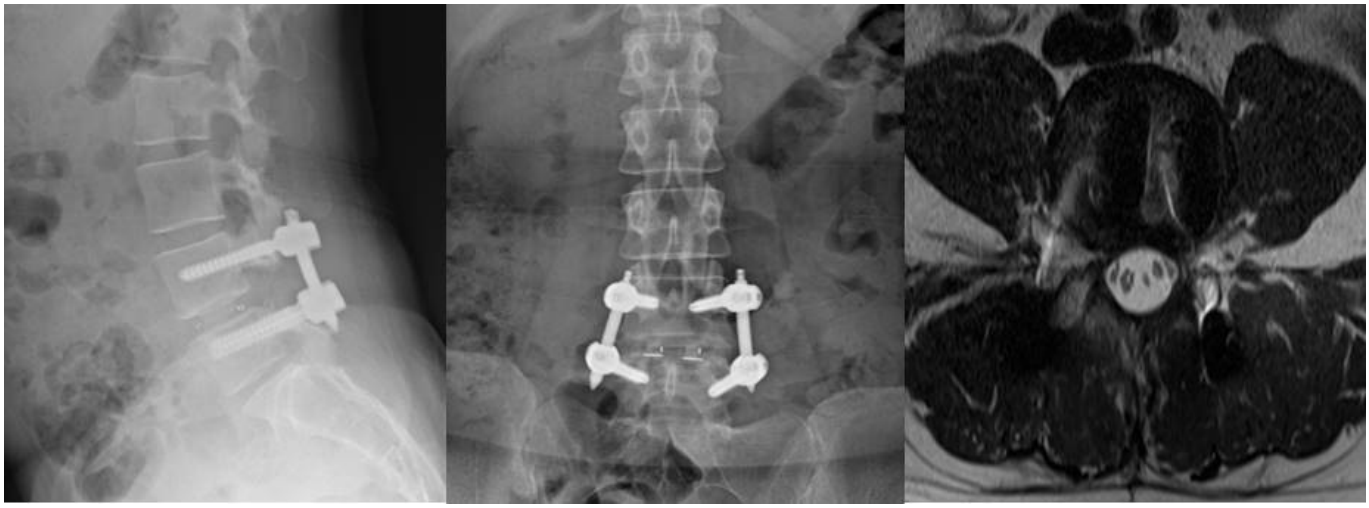

Figure 1. Illustrative case of mini-open PLIF of 46 years old female patients in the study group. Posteoprative MRI demonstrated absence of obvious paraspinal muslce atorphy at the index level.

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Stryker, Portage, MI, USA) filled with autograft bone and demineralized bone matrix (DBM; AllomatrixTM DR; Wright, Memphis, TN, USA) bilaterally. Additionally, percutaneous pedicle screws with a vertical axis and detachable extender (AnyPlus® MIS percutaneous pedicle screw system; GS Medical, Cheongju, Korea) were inserted under C-arm guidance.

For the study group, 3 mL of 3% atelocollagen (Coltrix® Tendoregen; Ubiosis, Seongnam, Korea) was injected at the paraspinal muscles. After the main operation procedures and layer by layer muscle closure, atelocollagen from a pre-filled syringe was injected at the paraspinal muscle using an 18 gauge needle, 1 cm from midline facial closure site bilaterally along the operation scar. Each injection points were at least 1 cm apart longitudinally and mean dosage of 0.2 mL was injected at each point (Figure 2). The subcutaneous layer and skin closure were followed accordingly after the injection. On the other hand, the same procedures were performed except atelocollagen injection after the muscle closure, in the control group. Bilateral submuscular drainage was inserted in all patients. Postoperatively, all patients were applied with routine 1-day intravenous antibiotics and were admitted for 2 weeks until wound stich out. The routine rigid back brace (usually lumbar-sacral orthosis) were applied to all patients for 3 months and typical postoperative managements such as medications; non-steroidal anti-inflammatory drugs, muscle relaxants etc. and physical therapy were administered.

Clinical efficacy was assessed by an independent third party, an experienced clinical study coordinator, who was blinded to all relevant knowledge of the patients, using a visual analog scale (VAS) for back pain.

Radiologic efficacy was evaluated with computer tomography (CT) with 3D reconstruction comparing images taken preoperative and 12 month postoperatively. The cross-sectional area (CSA) of multifidus and erector spinae muscles was measured in the mid-intervertebral index disc level at the axial CT image. The regions of interest (ROI) of individual muscles were measured by placing polygon points around the outer margins of the muscles to avoid metallic artifacts (Figure 3). The density

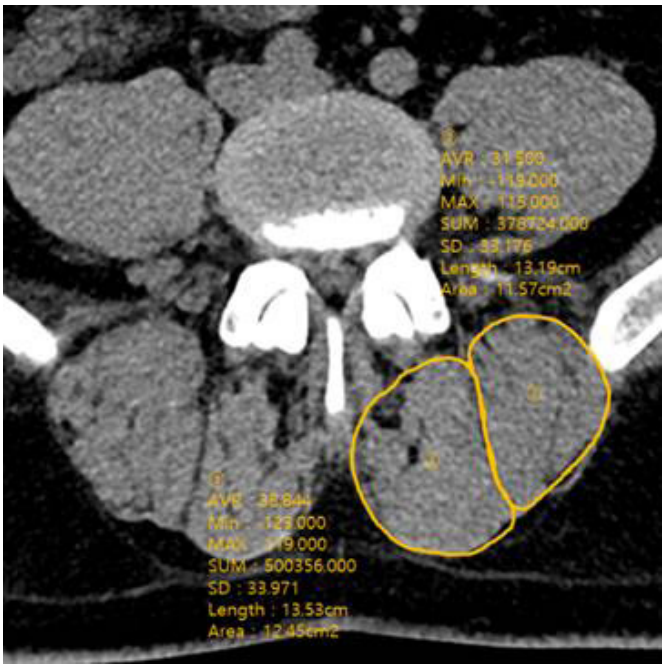

Figure 3. The cross-sectional area (CSA) of multifidus and erector spinae muscles was measured in the mid-intervertebral index disc level at the axial CT image.

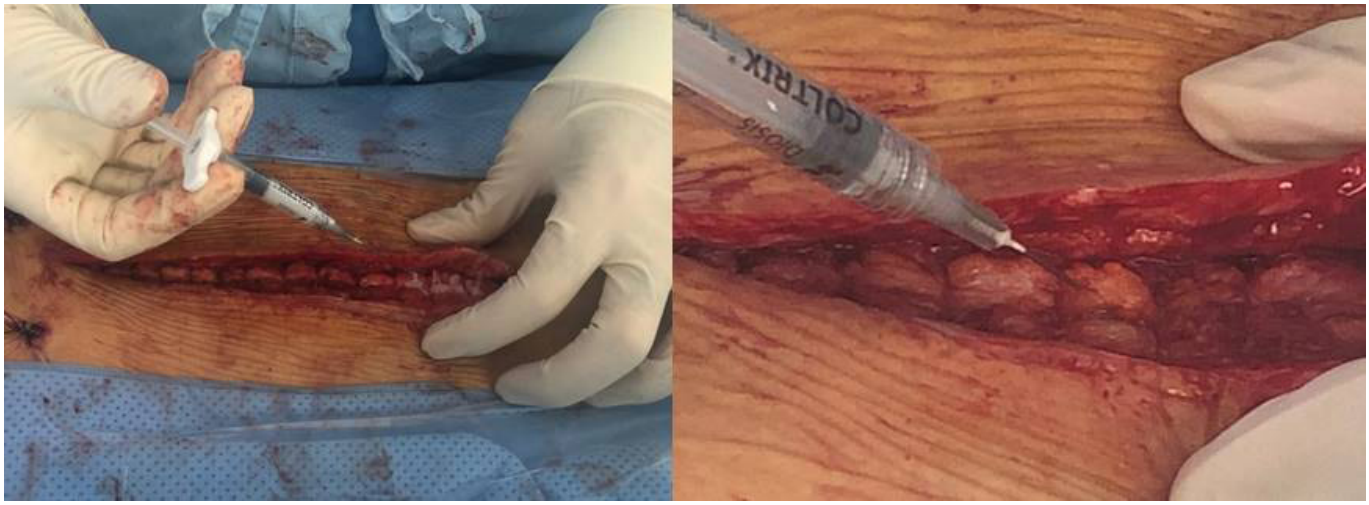

Figure 2. Injection of atelocollagen from a pre-filled syringe using an 18 gauge needle, 1 cm from midline bilaterally along the operation scar.

of the multifidus and erector spinae muscles was measured in Hounsfield units (HU) on both sides at mid- intervertebral index disc level and the mean value was obtained. It was evaluated by measuring the mean density in the ROI, using a 6-mm circle in the center of the muscle mass without visible fat deposits (Figure 4). The radiologic parameters were measured from L2-3 to L5-S1 level in each patient and the mean value was obtained for the statistical analysis. All radiologic measurement was done by observing the images obtained on a digital radiographic image displayed on a Picture Archives and Communication System (PACS terminal; nU PACS V. 1.0.0.36.17, 2019; Taeyoungsoft Inc., Anyang, Korea) and performed twice by two independent observers.

Laboratory examination including standard muscle enzymes (creatine kinase [CK] and lactate dehydrogenase [LDH]) and additional serum inflammatory markers (C-reactive protein [CRP] and erythrocyte sedimentation rate [ESR]) were performed in all patients. The safety was assessed with a survey and medical document review on all adverse events over 12 month.

The data were described as mean±SD. All statistical comparisons were 2-tailed, and the threshold for statistical significance was set at $p<0.05$. The inter-observer reliability was examined using 1-way analysis of variance, and the intra-class correlation coefficient (ICC). Regression logistic analysis was used to evaluate the correlation of CSA and muscle density with the patient's age, gender, BMI, smoking status and comorbidities.

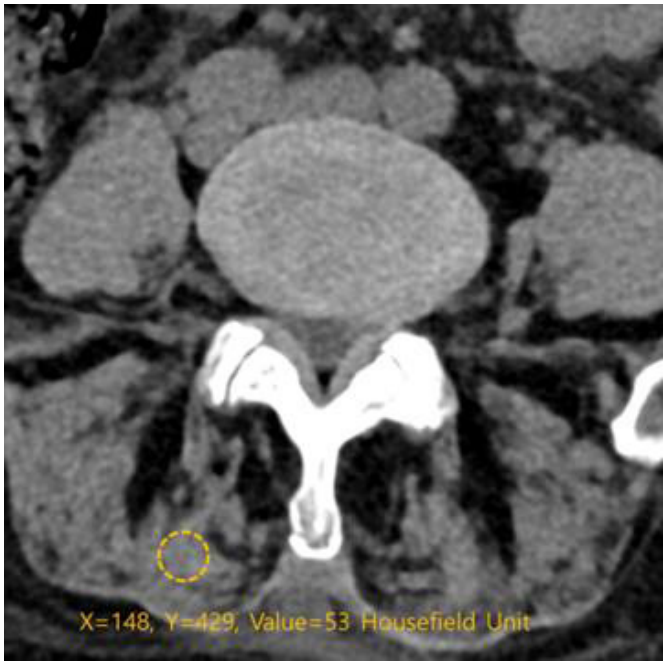

Figure 4. The density of the multifidus and erector spinae muscles was measured in Hounsfield units on both sides at the index level. It was evaluated by measuring the mean density in the region of interest, using a 6-mm circle in the center of the muscle mass without visible fat deposits.

RESULTS

A total of 118 patients received single level mini-open PLIF (60 men and 58 women) were retrospectively reviewed. The mean age at the time of the surgery were 65.4 years in the study group and 64.2 years in the control group. The most common operation level was L4-5 in the both groups. Patient demographics and perioperative data were described in Table 1.

Posteopratively, both group demonstrated statistically singnificant improvement of clinical outcome in mean 12 month follow-up. There was no significant difference in the VAS scores between the two groups in all time point (Figure 5).

Table 1. Patient demographics and intraoperative data

Characteristic	Study (n = 60)	Control (n = 58)	p-value
Gender			
Male	30 (50.0)	24 (41.4)	0.988
Female	30 (50.0)	34 (58.2)	0.074
Age (yr)	65.4 ± 11.9	64.2 ± 12.5	0.786
Preoperative symptoms			
VAS for back	7.9 ± 1.0	7.6 ± 1.5	0.578
VAS for leg	8.8 ± 2.1	8.7 ± 2.2	0.143
Symptom duration	12.9 ± 9.1	13.7 ± 8.2	0.170
Body Mass Index (kg/m^2)	27.7 ± 4.7	28.4 ± 5.1	0.261
Comobidities			
Hypertension	22 (36.7)	20 (34.5)	0.944
Diabetes	10 (16.7)	11 (18.9)	0.278
Osteoporosis	14 (23.3)	16 (27.5)	0.092
Smoking	5 (8.3)	6 (10.3)	0.114
Operation level			
L2-3	0	2 (3.0)	0.213
L3-4	14 (21.8)	18 (27.2)	0.115
L4-5	36 (56.2)	40 (60.6)	0.313
L5-S1	14 (21.8)	10 (15.1)	0.064
Intraoperative blood loss (mL)	221.5 ± 23.1	207.7 ± 31.9	0.368
Operating time (min)	152 ± 58	168 ± 41	0.928
Fluoroscopic time (sec)	3.8 ± 0.7	3.1 ± 2.2	0.459
Postoperative opioid use (mL)	8.8 ± 4.1	8.5 ± 3.8	0.203
Length of hospital stay (d)	8.6 ± 1.5	10.1 ± 1.7	0.362
Postoperative surgical drainage (mL)	176.2 ± 21.4	170.4 ± 19.9	0.892
Postoperative transfusion (mL)	94.1 ± 46.5	94.1 ± 26.4	0.640
Duration of follow-up (mo)	18.6 ± 5.2	20.3 ± 6.7	0.294

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

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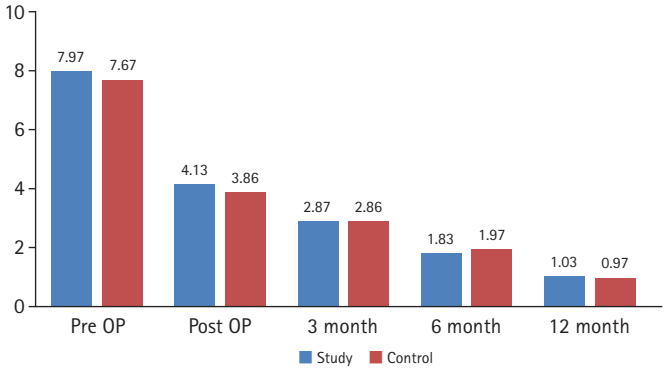

Figure 5. Posteoperative clinical outcome demonstration.

Table 2. Mean cross sectional area (CSA) and density of paraspinal muscles measured with computer tomography (CT) with 3D reconstruction

Characteristic	Study	Control	p-value
CSA			
Preoperative	7.54 ± 1.54	7.32 ± 0.81	0.761
Postoperative	7.17 ± 1.40	6.65 ± 0.74	0.093
Difference	0.37 ± 0.29	0.68 ± 0.27	< 0.001
Density			
Preoperative	64.67 ± 7.11	66.28 ± 4.74	0.309
Postoperative	61.77 ± 7.52	59.45 ± 4.80	0.162
Difference	2.9 ± 1.90	6.83 ± 2.22	< 0.001

Values are presented as mean±standard deviation.

There was no statistically significant difference in the mean CSA of paraspinal muscles between the study group and the control group and both group demonstrated singnificant decrease postoperatively. However, the reduction of

postoperative paraspinal muscle density was significantly lower in the study group (p<0.001; Table 2). Moreover, there was no statistically significant difference in the mean density of paraspinal muscles between the study group and the control group and both group demonstrated singnificant decrease postoperatively. The difference in pre- and postoperative density of the paraspinal muscles in the study group was significantly higher compared in the study group (p<0.001; Table 2).

The assessment of inter-observer reliability showed good agreement for the muscle volume (ICC=0.79), and excellent agreement for the muscle density measurement (ICC=0.92), indicating the measurements were reliable. In regression analysis, correlation between CSA and muscle density with demographic variables were not significantly associated.

The serum level of muscle enzyme and inflammatory markers demonstrated significant increment postoperatively in both groups, which gradually decresed until final follow-up. The amount of reduction in CK were significantly higher in the study group at 3 month, 6 month and 12 month, 6 month and 12 month in LDH. However, the differences of pre- and postoperative inflammatory markers between the two groups were not statistically significant during the entire follow-up period (Figure 6).

No procedure-related complications were observed during the entire follow-up period except two cases of subclinical infection treated with antibiotics without sequele in the study group.

DISCUSSION

Paraspinal muscle atrophy after lumbar spine surgery is an well-known cause of posteoprative axial back pain and adjacent segment degeneration [10-12]. The lumbar paraspinal muscle is important in maintaining lumbar segmental stability, and its defect and increased intramuscular fat infiltration are believed to cause disc degeneration [11,13]. Recently spine surgeons have tried to reduce iatrogenic paraspinal muscle atrophy by minimizing paraspinal muscle dissection using various methods [1,2]. Although, these minimally invasive surgical techniques seemed to be effective in maintaining the volume of paraspinal muscles after surgery to some degree, one cannot always use these techniques in numerous situations.

Muscle regeneration occurs in interrelated and time-dependent phases; degeneration, inflammation, regeneration, remodeling, and maturation. After initial degeneration phase, necrotic cell death stimulates a local inflammatory response [14,15]. The inflammatory response of injured skeletal muscle plays an important and critical role in muscle homeostasis and regeneration and involves the recruitment of specific myeloblastic cells within the injury site [16]. These inflammatory responses occur during 24 hours to 2 days after initial injury, followed by regeneration, remodeling and maturation phase. The dominant role in muscle regeneration is played by the muscle stem cells known as satellite cells, which reside between the basal lamina and sarcolemma of myofibers [15,17]. Satellite cells are activated in response to both physiological stimuli and pathological conditions to recruit myoblasts that can either fuse with existing myofibers repairing damaged muscle fibers, or alternatively fuse to each other to form new myofibers [18,19].

Theoretically local injection of Atelocollagen proliferate recruitment of myoblasts and satellite cell and act as scaffold for paraspinal muscles and fascial regeneration during inflammatory and regeneration phases [20-22]. Recent in vivo studies indicate that atelocollagen scaffolds provides a suitable

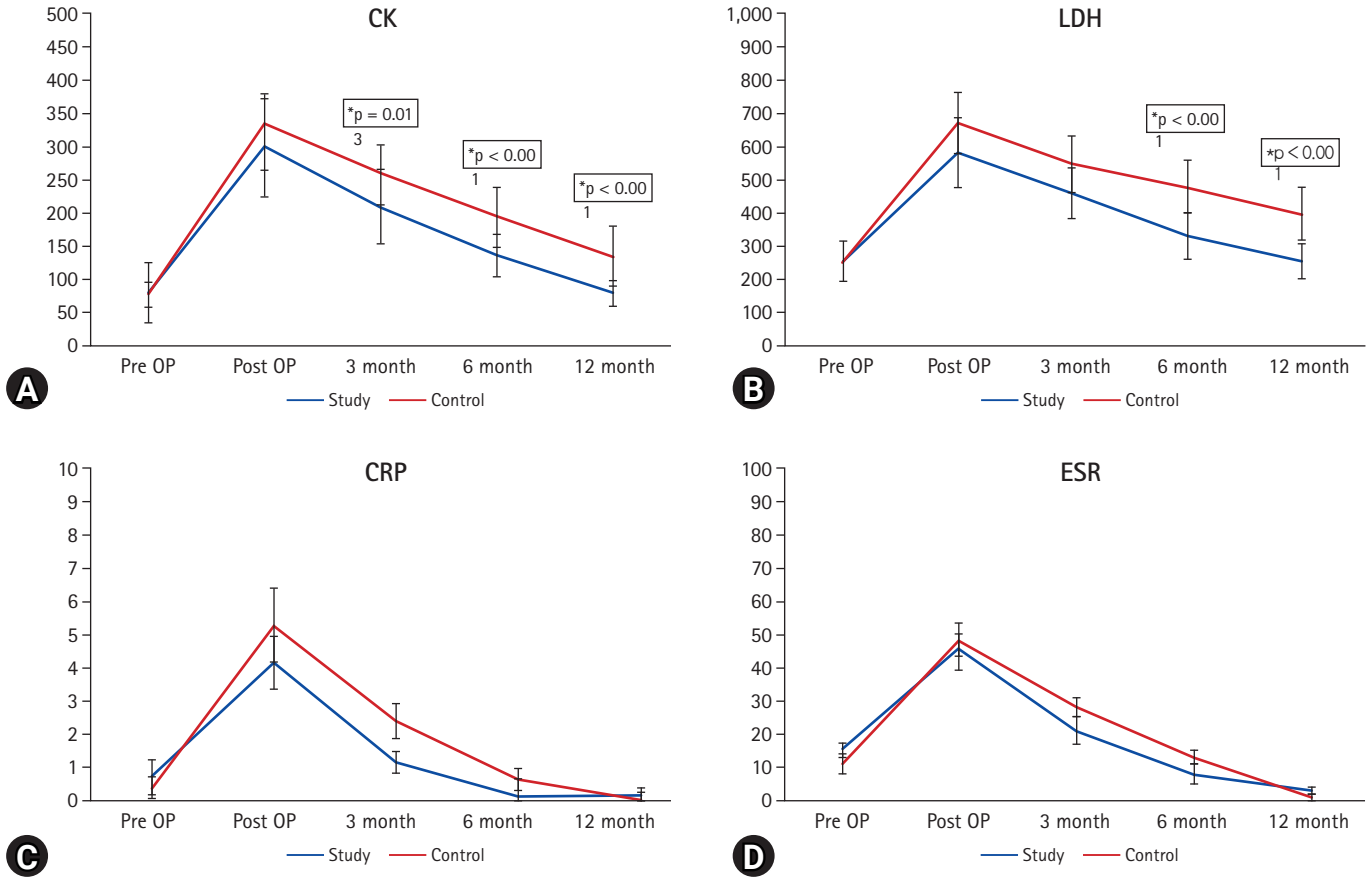

Figure 6. The serum level of muscle enzyme and inflammatory markers demonstrated significant increment postoperatively in both groups, which gradually decresed until final follow-up. The amount of reduction in muscle enzyme were significantly higher in the study. However, the differences of pre- and postoperative inflammatory markers between the two groups were not statistically significant during the entire follow-up period. CK: creatine kinase, LDH: lactate dehydrogenase, CRP: C-reactive protein, ESR: erythrocyte sedimentation rate, OP: operation.

substrate for mesenchymal stem cell attachment and enhancing chondrogenic differentiation [23,24]. However, the precise mechanism of healing effect after atelocollagen injection is yet to be clarified.

Several studies have demonstrated surgical role of atelocollagen and promising clinical results have been reported [8,16,21,23,25]. In a recent study using atelocollagen in orthopaedic surgery, Suh et al. [26] suggested repair after using patch-type atelocollagen between the torn rotator cuff and bone using rabbits. As a result, the group that used atelocollagen showed pathological and biomechanical superiority. However, uptodate there is not a single study about effect of atelocollagen injection on parapsinal muscle after spine surgery.

Our study demonstrated that injection of atelocollagen led to significant improvement in postoperative paraspinal muscles volume and density. These results suggest that atelocollagen injection after spinal surgery may be a viable option to reduce postoperative parapsinal muscle atrophy and enhance tissue healing. However, these radiologic findings did not affect clinical outcomes. The possible reasons are mainly because our study sample size is too small and mini-open PLIF is relatively less muscle invasive surgical technique using percutaneous pedicle screw fixation. Although there was no significant improvement of VAS score after injection of atelocollagen, this study proved initial safety of type 1 atelocollagen injection to paraspinal muscles as a clinical pilot study. Besides, the study group did not show inferiority compared with the control group regarding clinical and radiologic outcomes.

Our study has several strengths. This study is the first clinial trial examining the effect of atelocollagen injection on spine surgery. To our knowledge, this the first clinical pilot study to evaluate effect of atelocollagen injection on parapsinal muslce damage. Moreover, we used CT scan to precisely assess postoperative paraspinal muscle volume and density. Most of all, compared to other minimally invasive surgical techniques, the atelocollagen injetion is less time-consuming, more cost-effec-

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tive, and much easier method.

There are sevral limitations to this study. First, this study is a retrospective study and the sample size is maybe too small and follow-up period of 12 months maybe too short to assess the precise benefits of using atelocollagen. In the future, a prospective study with a larger sample size and longer follow-up period will be needed to validate the result of this study. Second, we could not find out the direct relevance between clinical improvement in VAS score and the volume of paraspinal muscle. Although, the obtained results were not statistically sginificant, further studies on the use of atelocollagen will be needed in the future.

CONCLUSION

Intramuscular injection of atelocollagen is safe and feasible method to prevent paraspinal muscle atrophy after spine surgery. This novel method seems advantageous for accelerating wound healing without causing harzadous inflammation. Prospective controlled trial with larger data samples are warranted in the future.

NOTES

Ethical statements

This study has been approved by the institutional review board of CMC, Catholic university of Korea (CMC IRB No. PC22RISI0010).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Clinical Article

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Minimally Invasive Transforaminal Lumbar Interbody Fusion with Enhanced Recovery after Surgery (ERAS): Early Experience with Initial Consecutive Cases at a Spine Naïve Community Hospital

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Objective: The objective of this study was to examine a spine naïve community hospital's ability to perform MITLIF safely and with speedy discharge via implementation of a minimally invasive spine surgery (MISS) program utilizing ERAS.

Methods: Single community hospital retrospective cohort analysis for initial consecutive MITLIF cases with unilateral pedicle screws performed by a single surgeon from October 2019 to March 2021. Minimum postoperative follow-up was one year. Narcotic use was assessed per the state prescription drug monitoring program. Surgery protocol included single paraspinal incision, non-expandable 18/22 mm tube, operating microscope, fluoroscopic guidance, EMG with SSEP monitoring and Enhanced Recovery After Surgery (ERAS) protocol.

Results: 52 patients were included. Average OR time, and fluoroscopy time were 143±115 minutes, and 1.00±0.47 minutes, respectively. Patients were prescribed an average of 38±33 post-operative opioid doses for an average of 8±7 days. All patients on preoperative, chronic narcotics had no prescription changes, pre-op versus post-op, despite clinical improvement. Complications included one irrigation a(1.9%) nd debridement with retention of hardware for surgical site infection, and one revision(1.9%) for displaced hardware. Discharge data included 47 (90.4%), four (7.7%), and one patients (1.9%) discharged on POD1, POD2, and beyond POD2, respectively.

Conclusion: MITLIF can be safely and successfully performed at a spine naïve community hospital with excellent intraoperative metrics, a low complication rate, and speedy discharge. MITLIF performed well in multiple perioperative and postoperative variables compared to MISS techniques. Considerations for implementation of MITLIF in the community setting include special equipment, personnel training, surgeon experience, ERAS protocols and diligent patient/ indication selection.

Key Words: Spine, Minimally invasive spine surgery, Outpatient surgery, Enhanced recovery after surgery, Surgery learning curve, Community spine surgery

INTRODUCTION

Minimally invasive spine surgery (MISS) is an area of active research aimed at improving patient outcomes compared to open spine surgery techniques. MISS approaches these goals by utilizing minimal openings and natural surgical planes to reduce surgical blood loss, perioperative anesthetic and analgesic requirements, and to preserve posterior motion segments and paraspinal muscles [1]. Developments in imaging guidance technology and instrumentation led to the introduction of a minimally invasive transforaminal lumbar interbody fusion (MITLIF) technique in 2002 [2,3]. The goal of the MITLIF approach is to avoid the destructive impact of the extensive retraction and muscular dissection required for a traditional open transforaminal lumbar interbody fusion (TLIF) [4,5].

Currently, there are limited large, high-quality studies directly comparing MISS and traditional open approaches in lumbar fusion surgery. In early investigations, however, MITLIF has performed well compared to open TLIF in terms of reduced morbidity [6-8]. Despite these advantages, a recent meta-analysis comparing MITLIF to open TLIF found a higher revision rate and readmission rate in the MIS group [9]. These risks, combined with expensive specialized equipment, and the substantial MISS learning curve have contributed to some spine surgeons noting implementation obstacles in their practice [9-12]. Additionally, there is a paucity of research regarding the ability of performing MITLIF in the outpatient setting and a lack of research regarding applying Enhanced Recovery After Surgery (ERAS) techniques to spine surgery [13,14]. ERAS protocols are multimodal perioperative care strategies aimed at accelerating post-surgical recovery by optimizing nutrition, standardizing analgesic/anesthetic regimens, and encouraging early mobilization [15-18]. ERAS holds significant promise for amplifying the benefits of MISS by reducing the direct and indirect cost and patient burden of inpatient postoperative care, but further study is needed [19].

Our study addresses these gaps in the current MISS literature by detailing our institution's implementation of both a MISS program and an associated ERAS protocol at a small, previously spine-naïve, community hospital. Our goal was to demonstrate that MITLIF, combined with an ERAS protocol, could be successfully implemented in the community setting without pre-existing perioperative spine infrastructure. The primary hypothesis is that MITLIF can be effectively performed in this environment and will result in excellent perioperative outcomes, early discharge, and a low complication profile. The secondary hypothesis is that MITLIF will perform well in comparison to other minimally invasive techniques performed in the same setting, which includes minimally invasive direct lateral interbody fusion (MIDLIF) and minimally invasive laminectomy with posterolateral fusion (non-interbody fusion, NIF).

MATERIALS AND METHODS

This retrospective chart review study was approved by the Institutional Review Board at the University of Pittsburgh.

1. Study Design

We conducted a retrospective chart review (level IV) of the initial consecutive cases performed between October 2019 to March 2021 by a single fellowship-trained orthopaedic spine surgeon. The setting for all cases was a university-affiliated community hospital with no in-house spine experience for over 10 years prior to this study. Inclusion criteria were patients that underwent a minimally invasive lumbar fusion procedure. These procedures included MITLIF, minimally invasive direct lateral interbody fusion (MIDLIF), or non-interbody fusion (NIF). All included patients were reviewed for demographic information including age, BMI, co-morbidities, indication for surgery, and gender. Perioperative information collected included total operative time, total radiation (fluoroscopy) time, surgery performed, complications, estimated blood loss (EBL), and any need for return to the operating room. Post-operative information collected included narcotics prescribed, length of hospital-stay, discharge disposition, and whether additional home health care was needed. Patient preoperative narcotic use was obtained via the Pennsylvania Drug Monitoring Program (PDMP). All patients included in this study had at least one year of follow-up available for review.

2. Treatment and Perioperative Protocol

Protocols included failure of nonoperative treatment modalities, which included over the counter medications, physical therapy, and interventional pain management. Surgical intervention included individualized patient-procedure matching with shared decision-making and pre-operative surgeon-guided education with counselling. Surgical technique included paraspinal/minimally invasive lateral lumbar surgery approaches. Surgical equipment utilized included a non-expandable 18/22 mm beveled and slotted tubular retractor ports, an operating microscope, and fluoroscopic guidance. Spinal monitoring was performed via EMG with SSEP. Spinal monitor-

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ing was used in all cases. Intraoperative and perioperative care followed an Enhanced Recovery After Surgery (ERAS) protocol. All cases included layered closure with barbed suture to reduce dead space, a local anesthetic consisting of bupivacaine administered along the wound bed in multiple small wheals, and a glue mesh waterproof dressing. Cases were performed without foley catheters, surgical drains, post-operative in-hospital imaging, or in-hospital dressing changes. For all patients, hospital medicine and occupational and physical therapy services were consulted on post-operative day (POD) 0. Laboratory bloodwork obtained on POD 1 included a complete blood count with a basic metabolic panel. Pain treatment included cold therapy, acetaminophen, methocarbamol, and narcotics as needed for breakthrough pain. Chronic pain prescriptions were maintained unchanged throughout patient hospitalization. Post-operative outpatient clinic follow-up visits were performed at 2 weeks, 6–8 weeks, and 16–24 weeks.

3. Statistical Analysis

The study power was set to 80% with an α=0.05. There were no missing values. The p-values were calculated from the likelihood ratio chi-square test for categorical variables including the subgroup difference in gender. Unpaired two-tailed t-tests were used to calculate p-values for continuous variables including average operating room (OR) time between subgroups. Linear regression was used for bivariate analysis with BMI.

RESULTS

1. Demographics

In total, 98 patients met criteria for inclusion. Patients were subdivided by surgical procedure performed. Group One consisted of 52 patients (53.1%) who had undergone MITLIF. Group Two consisted of 12 patients (12.2%) who had undergone MIDLIF. Group Three consisted of 34 patients (34.7%) who had undergone NIF.

Intergroup demographic comparisons included MITLIF versus NIF (Table 1) and MITLIF versus MIDLIF (Table 2). Patients in the MITLIF group were significantly younger than patients in the NIF group (66±12 years versus 73±10 years, p=0.005). Patients in the MITLIF group were similar in terms of gender distribution compared to the NIF group (28 females [53.8%] and 24 males [46.2%] versus 23 females [67.6%] and 11 males [32.4%], p=0.203). Patients in the MITLIF group had a significantly higher average BMI than patients in the NIF group (31.6±5.6 versus 28.9±5.1, p=0.027).

Patients in the MITLIF group were of similar age compared to patients in the MIDLIF group (66±12 years versus 67±6 years, p=0.797). Patients in the MITLIF group were similar in terms of gender distribution compared to the MIDLIF group (28 females [53.8%] and 24 males [46.2%] versus 7 females [53.8%] and 5 males [41.7%], p=0.778). Patients in the MITLIF group had a

Table 1. Intergroup comparisons between minimally invasive transforaminal interbody fusion (MITLIF) versus laminectomy with posterolateral fusion without interbody fusion (NIF)

MITLIF versus laminectomy with NIF	MITLIF	NIF	p-value
Baseline patient characteristics			
# of subjects	52 (53.1%)	34 (34.7%)	
Age (yr)	66 ± 12	73 ± 10	0.005*
Female (%)	28 (54%)	23 (68%)	0.203
BMI	31.6 ± 5.6	28.9 ± 5.1	0.027*
Co-morbidities			
Hypertension	31 (59.6%)	23 (67.6%)	
DM	11 (21.2%)	10 (29.4%)	
COPD	1 (1.9%)	2 (5.9%)	
CAD	3 (5.8%)	3 (8.8%)	
GERD	15 (28.8%)	7 (20.6%)	
Tobacco use	6 (11.5%)	0	
History of DVT	3 (5.8%)	1 (2.9%)	
Indication for surgery			
Stenosis	45 (86.5%)	34 (100%)	
Spondylolisthesis	39 (75%)	13 (38.2%)	
Disc herniation	12 (23.1%)	3 (8.8%)	
Procedural details			
OR time (min)	143 ± 115	118 ± 28	0.131
EBL (mL)	72 ± 44	73 ± 42	0.736
Radiation time (min)	1.00 ± 0.47	0.67 ± 0.48	0.003*
Radiation dose (rad)	4.23 ± 2.95	2.69 ± 2.15	0.007*
Post-operative day of discharge			
0	0	0	
1	47 (90.4%)	31 (91.2%)	
2	4 (7.7%)	3 (8.8%)	
>2	1 (1.9%)	0	
Avg	1.2 ± 0.9	1.1 ± 0.3	0.425
Discharge disposition			
Home w/self-care	28 (53.8%)	20 (58.8%)	
Home w/RN/PT	24 (46.2%)	12 (35.3%)	
SNF	0	2 (5.9%)	
Opioid use (per state PDMP)			
# opioid doses prescribed (5 mg oxycodone)	38 ± 33	37 ± 30	0.749
Duration of opioid prescription (d)	8 ± 7	8 ± 7	0.808

Table 2. Intergroup comparisons between minimally invasive transforaminal interbody fusion (MITLIF) versus minimally invasive direct lateral interbody fusion (MIDLIF)

MITLIF versus MIDLIF	TLIF	MIDLIF	p-value
Baseline patient characteristics			
# of subjects	52 (53.1%)	12 (12.2%)	
Age (yr)	66 ± 12	67 ± 6	0.797
Female (%)	28 (54%)	7 (58%)	0.778
BMI	31.6 ± 5.6	34.2 ± 6.6	0.217
Co-morbidities			
Hypertension	31 (59.6%)	7 (58.3%)	
Diabetes mellitus	11 (21.2%)	2 (16.7%)	
COPD	1 (1.9%)	1 (8.3%)	
CAD	3 (5.8%)	1 (8.3%)	
GERD	15 (28.8%)	1 (8.3%)	
Tobacco use	6 (11.5%)	0	
History of DVT	3 (5.8%)	0	
Indication for surgery			
Stenosis	45 (86.5%)	12 (100%)	
Spondylolisthesis	39 (75%)	7 (58.3%)	
Disc herniation	12 (23.1%)	0	
Procedural details			
OR time (min)	143 ± 115	190 ± 81	0.114
EBL (mL)	72 ± 44	78 ± 58	0.724
Radiation time (min)	1.0 ± 0.47	1.81 ± 1.11	0.028*
Radiation dose (rad)	4.23 ± 2.95	6.56 ± 6.32	0.236
Post-operative day of discharge			
0	0	0	
1	47 (90.4%)	9 (75%)	0.089
2	4 (7.7%)	3 (25%)	
> 2	1 (1.9%)	0	
Avg	1.2 ± 0.9	1.3 ± 0.5	0.747
Discharge disposition			
Home with self-care	28 (53.8%)	4 (33.3%)	
Home with RN or PT	24 (46.2%)	8 (66.7%)	
SNF	0	0	
Opioid use (per state PDMP)			
Number of opioid doses prescribed	38 ± 33	46 ± 32	0.470
Duration of opioid prescription (d)	8 ± 7	9 ± 5	0.787

similar average BMI compared to patients in the MIDLIF group (31.6±5.6 versus 34.2±6.6, p=0.217).

2. Intraoperative Data

Intergroup intraoperative comparisons included MITLIF versus NIF (Table 1) and MITLIF versus MIDLIF (Table 2). Patients in the MITLIF group had similar OR time (minutes) compared to the NIF group (143±115 minutes versus 118±28 minutes, p=0.131). Patients in the MITLIF group had similar EBL (mL) compared to the NIF group (72±44 mL versus 73±42 mL, p=0.736). Patients in the MITLIF group had significantly longer radiation time (minutes) compared to the NIF group (1.0±0.47 minutes versus 0.67±0.48 minutes, p=0.003). Patients in the MITLIF group experienced higher radiation dose (rad) compared to the NIF group (4.23±2.95 minutes versus 2.69±2.15 minutes, p=0.007).

Patients in the MITLIF group had similar OR time (minutes) compared to the MIDLIF group (143±115 minutes versus 190±81 minutes, p=0.114). Patients in the MITLIF group had similar EBL (mL) compared to the MIDLIF group (72±44 mL versus 78±58 mL, p=0.724). Patients in the MITLIF group had significantly less radiation time (minutes) compared to the MIDLIF group (1.0±0.47 minutes versus 1.81±1.11 minutes, p=0.028). Patients in the MITLIF group experienced similar radiation dose (rad) compared to the MIDLIF group (4.23±2.95 minutes versus 6.56±6.32 minutes, p=0.236).

3. Postoperative Data

Intergroup postoperative comparisons included MITLIF versus NIF (Table 1), and MITLIF versus MIDLIF (Table 2). The number of patients discharged in the MITLIF versus NIF groups was similar on POD 0 (MITLIF: 0 patients versus NIF: 0 patients), on POD 1 (MITLIF: 47 patients [90.4%] versus NIF: 31 patients [91.2%]), and on POD 2 (MITLIF: 4 patients [7.7%] versus NIF: 3 patients [8.8%], p=0.87). The average day of discharge was similar between groups (MITLIF: POD 1.2±0.9 versus NIF: POD 1.1±0.3, p=0.43). Discharge disposition did not differ significantly between MITLIF and NIF patients (MITLIF: 28 patients [53.8%] home with self-care, 24 patients [46.2%] home with RN/PT, 0 patients SNF versus NIF: 20 patients [58.8%] home with self-care, 12 patients [35.3%] home with RN/PT, 2 patients [5.9%] SNF, p=0.66, 0.38, 0.15, respectively). MITLIF patients required similar number of opioid doses (5 mg oxycodone tablet) postoperatively compared to NIF patients (38±33 versus 37±30, p=0.749). MITLIF patients required similar duration of opioid prescription postoperatively compared to NIF patients (8±7 days versus 8±7 days, p=0.808).

The number of patients discharged in the MITLIF versus MIDLIF groups was similar on POD 0 (MITLIF: 0 patients versus MIDLIF: 0 patients), on POD 1 (MITLIF: 47 patients [90.4%] versus MIDLIF: 9 patients [75%]), and on POD 2 (MITLIF: 4 patients [7.7%] versus MIDLIF: 3 patients [25%], p=0.089). The average day of discharge was similar between groups (MITLIF: POD 1.2±0.9 versus MIDLIF: POD 1.3±0.5, p=0.75). Discharge

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disposition did not differ significantly between MITLIF and MIDLIF patients (MITLIF: 28 patients [53.8%] home with self-care, 24 patients [46.2%] home with RN/PT, 0 patients SNF versus MIDLIF: 4 patients [33.3%] home with self-care, 8 patients [66.7%] home with RN/PT, 0 patients SNF, p=0.34). MITLIF patients required similar number of opioid doses (5 mg oxycodone tablet) postoperatively compared to MIDLIF patients (38±33 versus 46±32, p=0.47). MITLIF patients required similar duration of opioid prescription postoperatively compared to MIDLIF patients (8±7 days versus 9±5 days, p=0.79).

Of note, chronic opioid dependence did not change despite clinical improvement. There were 8 patients in the MITLIF group and 2 patients in the MIDLIF group taking chronic opioids pre-operatively who had no difference in post-operative chronic opioid prescriptions.

4. Bivariate Comparisons

Amongst MITLIF patients, radiation dose was directly correlated with BMI (R^2=0.1321). EBL (R^2=0.0865), OR time (R^2=0.0035), and opioid dose (R^2=0.0069) were not correlated with BMI.

5. Complications

Complications included one MITLIF patient (1.9%) who underwent an irrigation and debridement (hardware retained) for surgical site infection.

DISCUSSION

Key Findings

The primary hypothesis of this study is that MITLIF, combined with ERAS protocols, can be effectively performed in the community setting and result in excellent perioperative outcomes, early discharge, and a low complication profile. Our data largely supported this hypothesis. Patients undergoing MITLIF had low EBL (72±44 mL), with 90.4% of patients discharged on POD 1, and 100% of patients discharged to home. The secondary hypothesis in this study is that MITLIF will perform well in comparison to other minimally invasive techniques performed in the same setting, which was also supported by our data. The use of MITLIF did not significantly increase EBL, OR time, length of hospital stay, opioid dose, or opioid duration compared to patients undergoing NIF or MIDLIF.

A recent study performed in a large university setting, which compared MITLIF to open TLIF, reported a median length of hospitalization of 3 and 4 days, respectively (p=0.006) [8]. Of the three randomized controlled trials comparing MITLIF to open TLIF, only one specifically examined postoperative hospital length of stay, and did not find a significant difference (6.4±2.5 days versus 8.7±2.1 days, p=0.087) [20-22]. Thus, our data indicate that implementation of MISS with ERAS protocols at a community, previously spine-naïve hospital can produce excellent discharge disposition and timing after MITLIF, even compared to large academic centers. There is limited data regarding outcomes after truly "outpatient" MITLIF, and in this study, no patients were discharged after MITLIF on POD 0 [13]. However, given that the ERAS protocol was not specifically catered to drive outpatient discharge, and with the retrospective nature of the current data, it is difficult to speculate from this study on the ability to perform truly outpatient MITLIF. Given the very short average length of hospital stay and excellent outcomes, it may be reasonable to perform a prospective analysis in this setting examining outpatient MITLIF.

Average opioid dose and duration required for postoperative pain control was low (38±33 doses of 5 mg oxycodone for 8±7 days). A recent work comparing MITLIF to open TLIF reported postoperative opioid usage of 167 and 255 morphine milligram equivalents, respectively [23]. The total average opioid dosage required after MITLIF in this study, when converted to similar units, was lower, at 57±49.5 milligram morphine equivalents. Good pain control and the very low EBL in this study are likely in part from a rigorous implementation of ERAS protocols. One of the only studies examining the use of ERAS in the setting of MITLIF reported a significantly decreased length of stay and EBL in patients undergoing MITLIF with ERAS compared to patients undergoing the same surgery with conventional postoperative protocols [19]. A recent meta-analysis examining studies reporting data on operative time in MITLIF versus open TLIF did not find a significant difference, but did note significant heterogeneity between the studies [24]. Amongst the studies reported in this meta-analysis, the mean operative time in the MITLIF groups ranged from 104±26 minutes to 389.7±57 minutes [25,26]. Our reported average operative time of 143±115 minutes compares well to these averages. Amongst the studies reported in this meta-analysis, the mean blood loss reported in the MITLIF groups ranged from 50.6±161 mL to 466.7±199.4 mL [25,27]. Our reported average EBL of 72±44 mL compares well to these averages. Thus, in terms of postoperative pain control, operative time and EBL, our data indicate that MITLIF can be safely and effectively performed in a small com-

munity hospital with no prior spine experience.

The wide range of data reported in the MITLIF regarding important intraoperative and perioperative variables can partially be attributed to a commonly cited shallow "learning curve" that exists in MISS in general, and especially for MITLIF [9,11,28-30]. The main reported impacts of this learning curve are on operative time and rate of complications. A recent study that mapped the MITLIF learning curve data to a negative exponential function reported that 90% of expert level operative time was achieved at case 39 [11]. Over this same time span, the complication rate dropped from 33% to 20.5% [11]. Additionally, due to a likely selection bias stemming from surgeons frequently electing to operate on simpler cases in the early stages of their experience with MISS, the impact of the learning curve in MISS is possibly underreported [3,31]. With these factors in mind, it is important to note that the operative surgeon in our study has been performing MISS for over 10 years. Thus, although the surgical center itself and the perioperative staff from our study were naïve to spine surgery, the operative surgeon is well past the learning curve reported for MISS in the literature.

The strengths of this study include that all cases were performed by a single surgeon at a single surgical center, which decreases confounding variables related to differing surgeon experience level, differing operative techniques, and differing perioperative staff. The weaknesses of this study include the significantly higher average age and significantly lower BMI of the NIF Group compared to the MITLIF Group, making direct comparisons between these two groups somewhat difficult. These differences were due to the retrospective nature of this analysis. A higher BMI, in particular, has been cited in the MISS literature as leading to increased radiation exposure. This was consistent with our findings when comparing the higher BMI MITLIF Group, which had significantly higher radiation time and dose, to the lower BMI NIF Group. However, while this body habitus difference did not appear to impact operative time, nor EBL, the differing age makes these findings difficult to fully interpret at this time.

CONCLUSION

This is the first data collected from a series of MITLIF cases performed after the establishment of an MISS program with ERAS perioperative care in a previously spine-naïve setting. It demonstrates the ability of a single surgeon, who is past the MISS learning curve, to achieve an excellent safety profile both in the intraoperative setting, upon discharge to home, and within a year of surgery, with excellent pain control after MITLIF with ERAS protocols.

NOTES

Ethical statements

This retrospective chart review study was approved by the Institutional Review Board at the University of Pittsburgh.

Conflicts of interest

No potential conflict of interest relevant to this article.

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Target-oriented Percutaneous Lumbar Annuloplasty in Ambulatory Spine Center: Proctorship Description of Technique

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Objective: To describe an alternative technique of annuloplasty for treatment of chronic discogenic back pain in an ambulatory setting.

Methods: A retrospective review of all patients presenting with chronic discogenic low back pain and managed by target-oriented thermal annuloplasty at our institute from May 2015 to June 2019 was performed. The procedure is carried out under local anaesthesia in prone position. The principle of the technique relies on dividing the posterior annulus into nine equal segments on AP-view of the C-arm. The trajectory is through the Kambin's triangle in a horizontal trajectory as much as possible to target the posterior part of the disc annulus. Each of the nine segments is treated with radio-frequency probe to produce disc alterations required to relieve the pain.

Results: A total of 9 patients were treated by this method with an average follow-up of 28.1 ± 11.4 months. The average VAS improved from 4.1 ± 1.2 to 2.5 ± 0.4 at final follow-up. The ODI improved from 42 ± 6.7 to 19.98 ± 5.6. None of the patients had any complications. The patient satisfaction rate was 82%, the rate of return to daily life was 100% and recommendation rate to others was 100%.

Conclusion: Target-oriented lumbar percutaneous nine point annuloplasty may be considered as a viable option for chronic discogenic back pain patients with relatively well-maintained disc heights. A successful outcome depends upon proper patient selection and correct trajectory.

Key Words: Low back pain, Radiofrequency ablation, Intervertebral disc degeneration, Intervertebral disc displacement

INTRODUCTION

Low back pain is the most common complaint among patients with musculoskeletal disorders and has varied aetiologies including facet joint disease, spondylolysis, discogenic pain, disc herniations, etc. [1]. Discogenic pain may account for about 30–40% of these cases [2]. The management of these cases is difficult and often frustrating for the patient as well as the doctor. Many strategies have been proposed for treating back pain including, but not limited to drug therapy; multiple physical modalities like manipulation, physiotherapy, rehabilitation; interventional modalities like epidural injections, ozone injec-

tions, intradiscal electrothermal therapy, epiduroscopy and finally surgical options like fusion and artificial disc replacement. Most of these modalities have limited evidence and lack of consensus [3]. Often simultaneously and/or consecutively, more than one of these options have to be applied to a given patient. An ideal intervention for discogenic pain has to be effective, as little invasive, evidence based and cost-effective. However, such an ideal approach is hypothetical. Failure of conservative management is often an indication for surgery such as fusion, disc replacement or endoscopic discectomy. However, these procedures are not as effective and associated with significant costs, complications and morbidity [4-6]. Intradiscal electrothermal therapy involves applying heat to the posterior annulus through a catheter with a temperature-controlled heating coil. It proves to be a minimally invasive option whose effectiveness has been fairly substantive in the literature [7-12]. Numerous techniques of the procedure have been described. In this paper, the authors describe their technique of annuloplasty at nine different strategic locations on the posterior annulus using the DiscFx® system and report how this technique may be a better alternative than those described elsewhere.

MATERIALS AND METHODS

After obtaining permission from the institutional review board, we performed a retrospective analysis of patients treated at our institute from May 2015 to June 2019 for chronic discogenic back pain by target-oriented thermal lumbar annuloplasty (The Elliquence Disc-FX® System, Elliquence, LLC, Baldwin, NY, USA). Inclusion criteria were patients with chronic discogenic low back pain (>6 months), failed conservative treatment, pain aggravated on sitting and forward leaning (sitting intolerance) and reduced by standing and walking; and pain temporarily improved by epidural steroid injection. Patients with frank disc herniation, leg pain and those treated by other methods such as fusion were excluded. The data were analysed to find the demographic data such as age, sex, presenting complaints; clinical data included VAS (visual analogue scale) for back pain and ODI (Oswestry disability index) at pre-op, post-op and 1, 3, 6 months and 1-year follow-up. The MRI records were analysed to identify the levels affected.

1. Indications

The key to a successful outcome is proper patient selection. The selection criteria includes following:

- Patients with non-radicular, chronic low back pain (>3 months), not relieved conservatively. A typical patient with discogenic pain has aggravated pain on flexion, sitting intolerance and a catch on active extension of the spine.
- Negative neurological signs including straight leg raise test (SLRT), normal power, tone, sensation and reflexes of lower limbs
- The MRI should show a degenerative disc disease with a hyper-intense zone (HIZ) in the posterior annulus, without evidence of disc herniation or canal stenosis or facet arthrosis. The disc protrusion should be <5 mm and disc height should be at least 50% of the adjacent levels

A positive provocative discogram- the role of a discogram is controversial and the author do not recommend it. However, it may be recommended for ambiguous cases. A discography helps to analyse the disc architecture and the target points for ablation.

2. Pre-operative Assessment

The first modality of treatment in a chronic, axial back pain patient in our clinic is a medial branch block (MBB). This helps us to identify a component of facet joint pain in these patients [13]. If the pain relief by MBB is insignificant, the next modality is an epidural block. If an epidural block is effective, it can be repeated up to 2 times [14]. For long term benefits, an option of annuloplasty is offered to the patient in whom epidural block relieves the back pain significantly. Our workflow is shown in Figure 1.

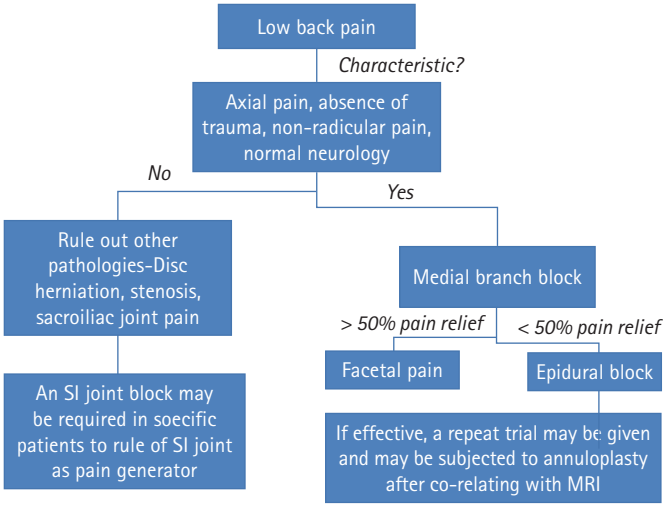

Figure 1. Flow-diagram depicting the step-wise management of chronic discogenic low-back pain patient.

3. Relevant Surgical Anatomy

The knowledge of Kambin's triangle forms the foundation for all transforaminal procedures. Kambin's triangle is a window of entry into the lumbar spinal canal. It is dorsolateral to the spinal canal and bounded medially by the traversing nerve root and the superior articular process; the base is formed by the superior endplate of caudal vertebrae and the hypotenuse is formed by the exiting nerve root. The trajectory for needle placement is planned on MRI as is done in endoscopic procedures [15].

4. Analysis of the Pain Generators and Planning the Needle Trajectory

The MRI should be carefully evaluated to find the hyper-intense zone of inflammation that is the cause of pain in these conditions. We believe that there are three components to a disc protrusion as described in Figure 2. The innermost portion is the desiccated and degenerated nucleus pulposus, a fissured tract along the annulus and the terminal portion is the disc protrusion. Targeting of all three components is essential for a successful outcome of the procedure. Whereas a conventional IDET (intradiscal electrothermal therapy) targets the central disc, our method targets the pain generating intra-annular and sub-annular part of the disc. Hence, our technique requires the needle to be introduced in a more horizontal manner compared to the conventional IDET techniques. This helps us to target the pain generating sub-annular and intra-annular portions. A difference in the approach of conventional IDET and our technique is shown in Figure 3.

5. Technical Details

The patient is positioned prone on a Wilson frame over a radio-lucent table. A combination of local anaesthesia and conscious sedation is utilized as an out-patient procedure. Under C-arm guidance, mark the midline, the iliac crest, and the rib cage. Next, mark the transverse disc line in AP view. Then, in lateral view, draw a line parallel to the disc space. The intersection of the first and the second line is the entry point. Before making the skin incision, it is essential to palpate the lateral border the back muscles and avoid entry lateral to it as it may cause abdominal organ injury. First, place the needle in the epidural space and inject a radio-opaque dye to delineate the dural sac and the nerve roots. Then withdraw the needle and advance it deeper into the disc so that the tip of the needle lies in the center of the disc in AP view and in the posterior annulus in lateral view. Inject a small amount of dye to confirm the location of the needle. A concordant pain will be elicited. A guide-wire is put in the spinal needle and the needle is removed. Then, a dilator is placed over the guide-wire and the cannula is inserted. At this point, the cannula and the dilator are at the outer surface of the annulus. The dilator is removed and a trephine is inserted in the cannula. By gentle rotations of the trephine, the annulus is cut and the trephine is advanced to the midline. The cannula is then advanced over the trephine. Remove the trephine and reintroduce the dilator to enlarge the annular tract. The position of the guide-wire, dilator and the cannula is verified by C-arm. Remove the dilator and the guide-wire and use the cannula as the working channel. With the help of a disc punch, remove the disc material from the midline. First introduce the disc punch with the jaw opening ventrally

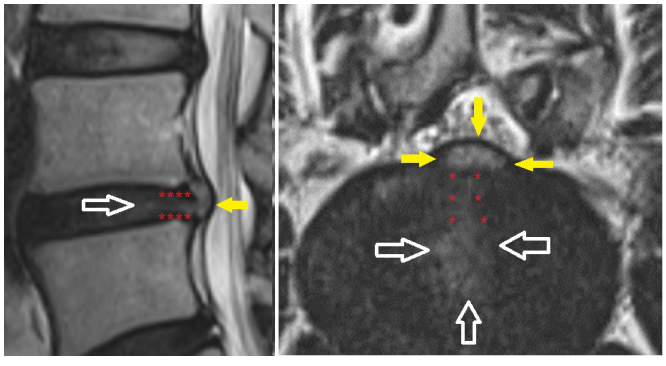

Figure 2. Sagittal and axial view of an L4-5 degenerative disc disease showing the three pain generating components. White arrows show the degenerated nucleus pulposus, red asterisks show the tract of herniation and yellow solid arrows show the bulging disc.

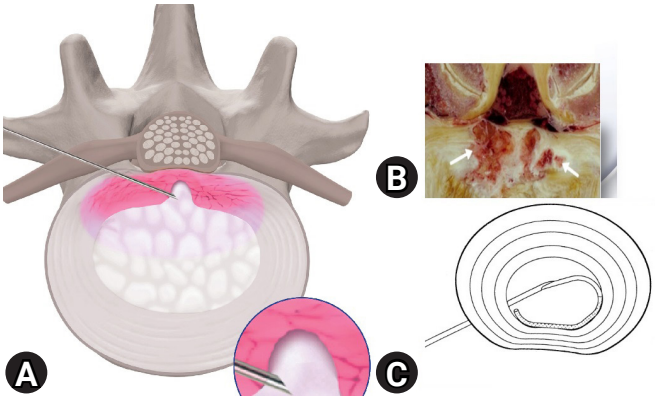

Figure 3. (A) Show the ideal target oriented trajectory as described in our technique, (B) pathological specimen showing pain-generators in the posterior annulus (described by white arrows) and (C) conventional IDET method.

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and grasp the tissue to be removed. Then rotate the disc punch by 180° and remove the disc from the dorsal side. This is done under C-arm guidance. Now introduce the electrothermal probe for ablation. The system is a bipolar electrode with a saline flowing from the tip of the electrode. The power is set at "25" and the probe is pressed against the tissue for 6 seconds under "turbo" mode. It is important to note that during this process, the bevel of the cannula faces ventrally. Squeezing the handle makes the bipolar electrode extend out of the distal end of the shaft and point upward. This allows the bipolar tip to be guided as required. This procedure will be repeated 6 times; once at 12, 2, 4, 6, 8, and 10 o'clock sequentially. In the nine point annuloplasty part, the bipolar hemo (blue pedal) is used. The probe is held in the vertical position so the tip will come out and up (dorsally). The tip will be rubbing along the internal portion of the annulus where the disc is bulging. Squeeze and hold the handle to perform three 6 seconds sweeps using a sawing motion at 11:00, 12:00, and 1:00. This can be performed at 9 target points in the center, ipsilateral and contralateral part of the disc. These locations are center cranial, center central, center caudal, contralateral cranial, contralateral central, contralateral caudal, ipsilateral cranial, ipsilateral central, ipsilateral caudal.

A diagrammatic representation of the procedure in shown in Figure 4. The 9 point as seen on C-arm are showing in Figure 5. After the procedure, the patient is observed for about 3 hours in the ambulatory spine care setting and can be discharged on the same day. A lumbosacral orthosis is given for 3–4 weeks. The pain is expected to flare up in the initial few weeks which subsides gradually. Forward bending is allowed after 3–4 weeks. Back range of motion and strengthening exercises are advised after 6 weeks. Heavy work is usually avoided for 6 months.

RESULTS

A total of 9 patients (5 males and 4 females) were included in the study with an average follow-up of 28.1±11.4 months. There were 6 patients who had the procedure at L4-5 level and one patient each at L2-3, L3-4, and L5-6. The average VAS improved from 4.1±1.2 to 2.5±0.4 at final follow-up. The ODI improved from 42±6.7 to 19.98±5.6. None of the patients had any complications. The patient satisfaction rate was 82%, the rate of return to daily life was 100% and recommendation rate to others was 100%. The MacNab criteria were excellent in 7 and good in 2.

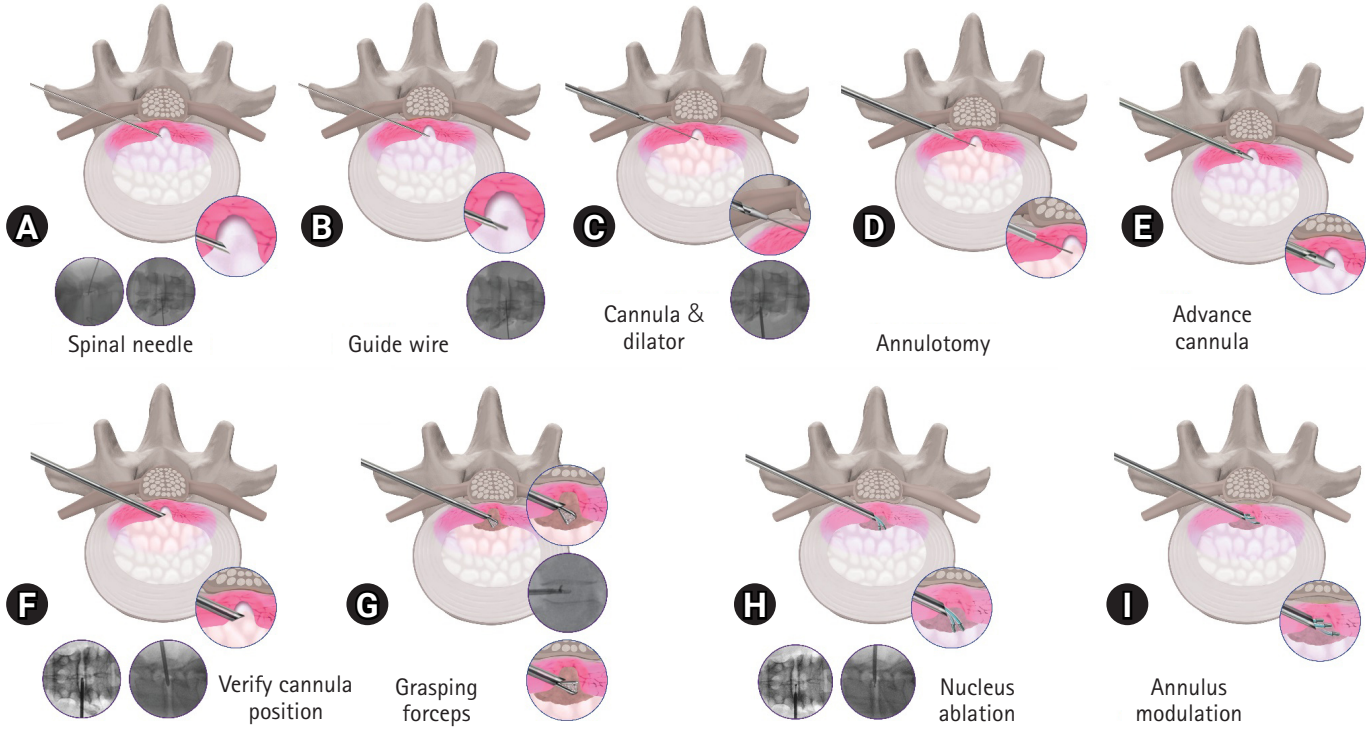

Figure 4. Schematic diagram showing step-wise procedure. (A) Spinal needle insertion; inset showing epidurography; (B) guide wire insertion; (C) insertion of dilator and cannula over the guide wire up to the outer surface of annulus; (D) annulotomy with a trephine; (E) advancement of cannula below the center of the posterior annulus; (F) verifying the correct position of the working cannula under C-arm (shown in inset); (G) grasping forceps is used to remove parts of disc to create a working space; (H) the radio-frequency probe is inserted, and then the nucleus and the tract of herniation are ablated; (I) annuloplasty/annulus modulation.

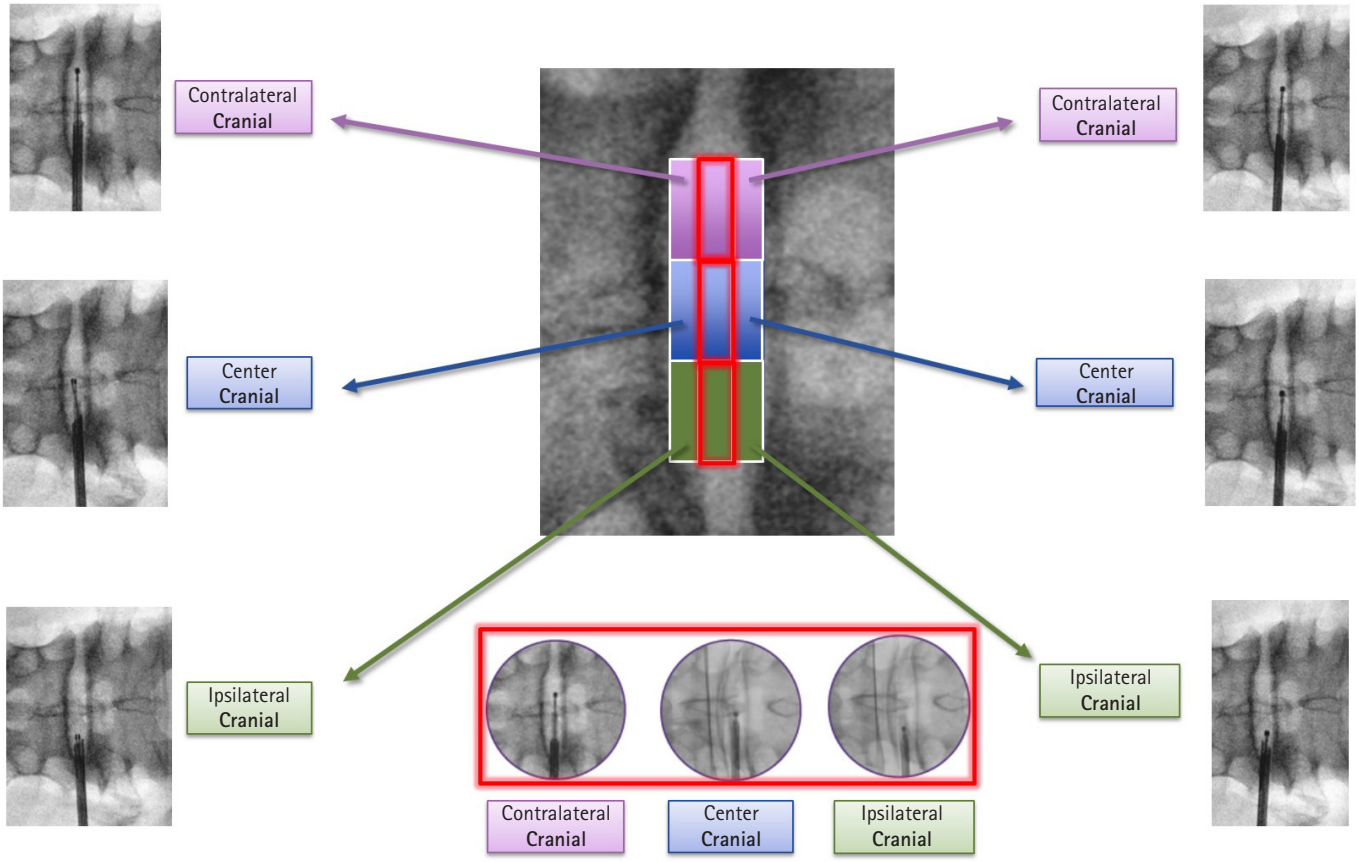

Figure 5. The 9 segments of the posterior annulus as seen on C-arm image which are targeted one by one for annulus modulation.

Representative Case Example

A 28 years old male patient with chronic low back pain and sitting intolerance presented to us. He had tried all conservative options but failed to get a permanent relief. His VAS back was 6. The pain was relieved on supine posture. A standing lateral X-ray of the lumbar spine showed reduced segmental lordosis at L4-5. An MRI of the lumbar spine showed a degenerative disc disease at L4-5 level with no canal stenosis or root compression. A nine point annuloplasty relieved his symptoms. At 3-month follow-up, his VAS reduced to 2 and completely relieved at 6-month follow-up. The patient satisfaction with the procedure was good. Follow-up X-rays showed improvement in the segmental lumbar angle and whole lumbar lordosis. The radiographic images are depicted in Figures 6,7.

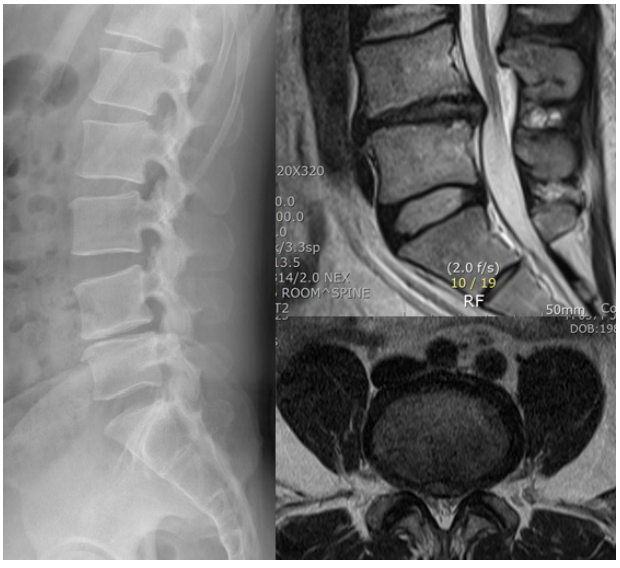

Figure 6. Pre-operative images of a 27-year old male with chronic low back pain since 2 years ago. Visual analogue scale for back was 5 out of 10. There was no leg pain. The patient had been subjected to epidural steroid injections twice in the past two years and obtained reasonable short term relief. X-ray and MRI shows degenerative disc disease at L4-5 level.

DISCUSSION

Ever since the first description of this procedure in 2000 by Saal and Saal [10], numerous reports have been described in the literature regarding electrothermal therapy. Various tech-

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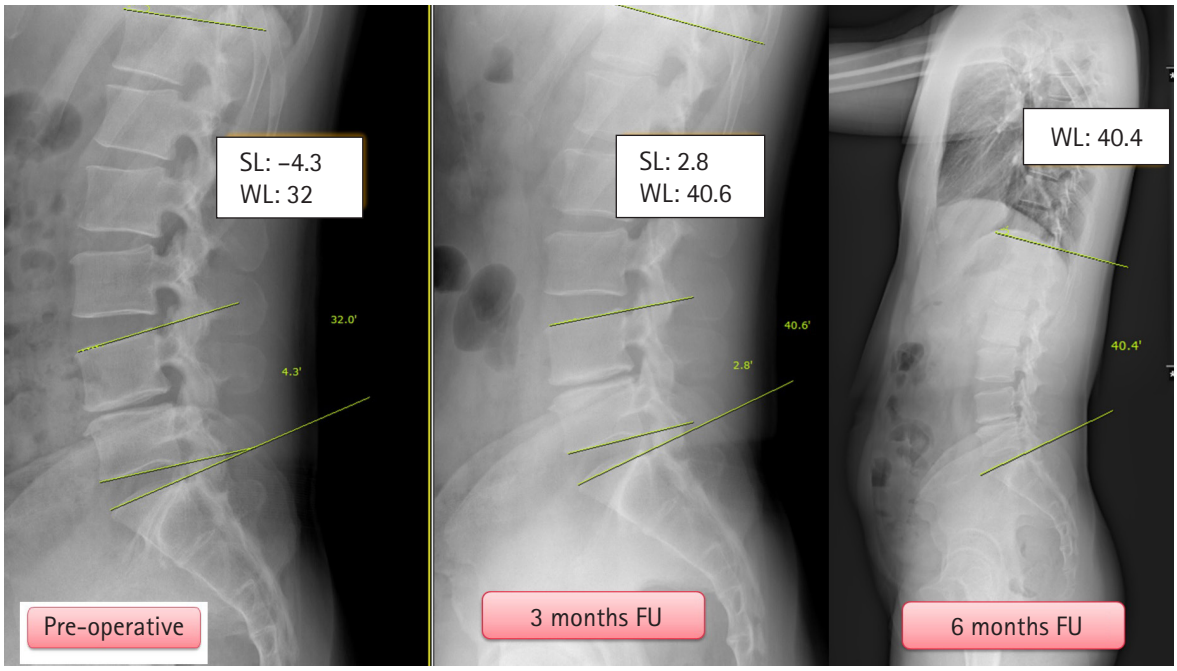

Figure 7. Comparison of pre-operative and follow-up images to show improvement in the spinal sagittal parameters, lumbar lordosis and segmental lordosis. VAS improved to 0 out of 10 at 6-month follow-up.

niques have used thermal, bipolar, laser and radio-frequency probes as modes of coagulation. Although the exact mechanism of action is unknown, various theories postulate that the heat causes denaturation of collagen leading to increased stiffness, ablation of the nociceptors and shrinkage of the size of the annular defect leading to decreased secretion of pain generating chemo-mediators [16]. The heat required to produce these changes in the disc architecture has been determined to be in the range of 60–75 degrees C in various studies [17,18]. The conventional IDET involves placement of the needle in the center of the disc and negotiation a long probe in a circumferential manner into the sub-annular area for coagulation [8,12,19,20]. However, with various in-vivo and in-vitro studies, it was concluded that the central placement of the probe was undesirable since the pathology is in the posterior annulus [21].

Our technique of nine point annuloplasty ensures that the entire posterior annulus which is the site of pain generating receptors is effectively dealt by the coagulation therapy. All our patients improved significantly with respect to VAS for back and ODI. The procedure can be applied as a day-care procedure with good patient acceptability and high satisfaction rates and minimal complications. The sequential ablation by diving the entire posterior annulus into 9 quadrants is helpful so that no part is left untouched and thus ensuring the adequacy of ablation. The principal difference with our technique is the trajectory of the needle and the probe placement. A more horizontal approach puts the device in close proximity to the pathology. A central placement of the device, as in conventional IDET, is not sufficient to generate enough heat at the site of pathology [16,17,22]. The heating effect of the probes is negligible beyond 6 mm radius from the device. The temperatures produced are capable of inducing changes only in 1–2 mm radius from the device [17]. Thus placement of the probe according to our technique is a more target-oriented approach to the pathology. Furthermore, the central nucleus is not damaged by this approach. The three components of the DDD, the desiccated nucleus, the fissured tract as well as the annular bulge, all three can be dealt by our technique. Although the alteration of the disc architecture may alter the biomechanical properties of the affected segment, cadaveric studies have failed to demonstrate the same and conclude that the heat therapy does not destabilize the vertebral segment [18,23].

Literature support favoring electrothermal therapy is fairly sufficient with numerous level 1 evidences. We believe that the key to a successful outcomes depends upon proper selection criteria and proficient execution of the procedure. A multimodal approach, with supervised physical therapy, ergonomic modifications and psychosocial rehabilitation are essential for a good outcome. Although fusion and disc replacement have been described in literature for management of these conditions, the lack of high quality evidence regarding their efficacy and the morbidity and cost associated with these technique

Table 1. Summary from the NASS guidelines depicting the grade of recommendation of intra-discal thermal annuloplasty for low back pain

Interventional Question 12.	Intradiscal electrothermal annuloplasty is suggested to provide improvements in pain and function at up to two years. This treatment is limited in its effectiveness with roughly 40–50% of patients receiving a 50% reduction in pain.
In patients with low back pain, does intradiscal electrothermal therapy or biacuplasty decrease the duration of pain, decrease the intensity of pain, increase the functional outcomes of treatment and improve the return-to-work rate?	Grade of recommendation: B
	Biacuplasty is an option to produce clinically and statistically significant improvements in pain at 6 months in patients with discogenic low back pain.
	Grade of recommendation: C
	There is insufficient evidence to make a recommendation for or against the use of percutaneous intradiscal radiofrequency thermocoagulation.
	Grade of recommendation: I

warrant further investigation [24]. Annuloplasty, on the other hand, has fewer complications and is minimally invasive. The procedure is quite safe with experienced hands. The North American Spine Society guidelines for management of low back pain also state that "Intradiscal electrothermal annuloplasty is suggested to provide improvements in pain and function up to 2 years. This treatment is limited in effectiveness with roughly 40–50% of patients receiving a 50% reduction in pain". A reference table from the NASS guidelines is quoted (Table 1).

Four randomized control trials comparing electrothermal therapy with placebo have been published. Three out of four provide sufficient reinforcement to this technique [7,9,16,25]. Desai et al. [7] performed a prospective multi-center RCT comparing intradiscal biacuplasty with medical management for discogenic lumbar back pain and found superior results with electrotheramal therapy. However, this study involved placement of bilateral probes for ablation. Pauza et al. [9] randomized 64 patients and found better improvements in pain, disability and depression in the IDET group. Karasek and Bogduk [26] reported their 12-month follow-up of controlled trial of IDET for discogenic back pain in 53 patients. They concluded that 54% of the patients reduced their pain by half and 1 in 5 patients had complete relief. Apart from these, numerous observational studies also provide significant evidence of its efficacy [4,10-12,19,20,27,28]. Saal and Saal [11] reported IDET in 62 patients who were followed up for 2 years and showed favorable outcomes. Although the complication rate is low, they have been described in literature and include discitis, catheter breakage, root injury, vertebral osteonecrosis, trans-thecal puncture, cauda equina syndrome.

Contra-indications and Limitations

The procedure is contraindicated in presence of instability, frank disc herniation, stenosis (greater than Grade B of Schizas classification [25]) and in those who had surgery at the same level in the past 6 months. Familiarity with the transforaminal anatomy is essential to carry out the procedure safely. Also, in cases with a high iliac crest, it is difficult to obtain a satisfactory positioning of the probe.

CONCLUSION

Being a minimally invasive option, nine point annuloplasty may be considered as a viable option for chronic discogenic back pain patients with relatively well-maintained disc heights and protrusions less than 5 mm. It is a more target-oriented approach and preserves the central nucleus. A successful outcomes depends upon proper patient selection and correct trajectory.

NOTES

Ethical statements

This study has been approved by the institutional review board of Seoul Saint Mary's Hospital, Catholic university of Korea (KC16OISI0254).

Conflicts of interest

No potential conflict of interest relevant to this article.

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Technical Note

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Full Endoscopic Interlaminar Contralateral Lumbar Foraminotomy for Recurrent L5-S1 Foraminal-extraforaminal Stenosis: A Case Report with a Technical Note

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After endoscopic lumbar foraminotomy, decreased disc height commonly causes foraminal restenosis and accompanying lateral recess stenosis. Interlaminar contralateral endoscopic lumbar foraminotomy can be used to treat multiple recurrent lesions instead of fusion surgery. Dorsal foraminal-extraforaminal decompression is challenging because of severe perineural adhesions. Therefore, neural decompression should be focused on the ventral foraminal expansion along the virgin dissection plane between the exiting nerve root and ventral foraminal pathologies. The prominent bony spur and herniated disc were removed using an endoscopic drill and forceps. As the foramen was enlarged, the endoscope was introduced deeper through the caudal-ventral foramen space to explore the extraforaminal and far-out lesions. Postoperatively, neurological deficits of L5 radiculopathy and radiating leg pain improved. The expanded foraminal-extraforaminal space was well maintained without progression of lateral wedging on the one-year follow-up images. We successfully treated recurrent foraminal-extraforaminal stenosis and combined lateral recess stenosis using the full endoscopic interlaminar contralateral approach at the L5-S1 level. This technique may be an alternative surgical method to treat the recurrent foraminal-extraforaminal stenosis in the collapse of the L5-S1 neuroforamen. However, this technique should be considered in highly selected patients unsuitable for fusion operations.

Key Words: Lumbar vertebrae, Endoscopy, Vertebral foramina, Spinal stenosis, Endoscopy

INTRODUCTION

The lumbar exiting nerve roots (ENR) pass through the neuroforamen below the pedicle and superior articular process (SAP), then curve downward in the far-out area. ENR entrapment in the foraminal and extraforaminal areas is usually caused by a hypertrophied ligamentum flavum and enlarged facet joints. The prominent syndesmophytes and herniated disc also compress the ENR from the ventral region and distort the ENR course in the far-out area.

The lumbar paraspinal or transforaminal endoscopic approach is commonly used to resolve foraminal and extraforaminal stenosis if conservative treatment fails. As the disc height decreases after foraminotomy, lateral recess stenosis develops,

and restenosis of the foraminal-extraforaminal area occurs. These combined lesions cause the symptom recurrence, and a lumbar fusion operation is usually performed to resolve the recurrent ENR compression and combined lateral recess stenoses. However, lumbar fusion surgery is occasionally inappropriate for old, medically debilitated patients, and alternative surgical options are considered to treat combined and recurrent pathologies.

An advancing endoscopic approach was recently developed to treat contralateral coexisting lateral recess stenosis and foraminal and extraforaminal stenosis via a unidirectional interlaminar contralateral approach using full endoscopy and biportal endoscopy [1-3]. This technique showed favorable outcomes in the lumbar levels and reported more benefits at the L5-S1 level [3-5].

We successfully performed a full endoscopic interlaminar contralateral lumbar foraminotomy as an alternative surgical option to treat combined lateral recess stenosis and recurrent foraminal-extraforaminal stenosis in an elderly patient with severe medical problems. Expanded spaces at the lateral recess and foraminal and extraforaminal areas were well maintained in the one-year follow-up images without progression of lateral wedging.

This study was approved by the institutional review board (approval No. 2202-W03).

CASE REPORT

1. Case Presentation

An 82-year-old male presented with a 10-month history of gradually progressive motor weakness in his right leg. The patient complained of radicular pain in the right leg through the L5 dermatome despite 5 months of conservative treatment. He showed intermittent neurogenic claudication after 10 minutes of walking. Magnetic resonance imaging (MRI) and computed tomography (CT) showed lateral recess stenosis at the right side of the L4-5 level and foraminal-extraforaminal stenosis at the right side of the L5-S1 level (Figure 1A–F). Due to lateral recess stenosis, the patient underwent full endoscopic decompressive laminotomy at the right side of the L4-5 level (Figure 1G). A full endoscopic transforaminal approach was also performed at the right side of the L5-S1 level to treat the foraminal and extraforaminal stenosis (Figure 1H–M). Preoperative symptoms significantly improved after the surgery. There was no recurrence of symptoms during the three-year follow-up period. However, he revisited the hospital because of a recurrence of the symptoms that gradually progressed in his right leg. Despite 5 months of conservative treatment, the patient complained of buttock and radicular pain in the right leg through the L5 and S1 dermatomes. Neurological examination revealed hypesthesia of the posterolateral aspect of the lower leg. The motor power of his ankle dorsiflexion decreased to grade 4 (out of 5). MRI and CT revealed lateral recess stenosis and restenosis of the foraminal-extraforaminal space on the right side of the L5-S1 level (Figure 2A–G). In his past medical history, the patient had type 2 diabetes mellitus, hypertension, cerebral lacunar infarction, and coronary vascular disease. He had undergone two stent procedures for coronary vascular disease 1 year after the first decompressive surgery. This patient refused lumbar fusion surgery because of a previous history of cardiovascular and cerebrovascular diseases. Furthermore, revision transforaminal surgery for foraminal-extraforaminal restenosis might cause severe ENR injury. Therefore, we recommend a full endoscopic interlaminar contralateral approach to simultaneously treat coexisting contralateral lateral recess and foraminal-extraforaminal recurrent stenoses (Figure 2H– N).

2. Operation Technique

A full endoscopic interlaminar contralateral approach was performed with the patient in the prone position on the Wilson frame under epidural anesthesia. The full endoscopic system, 15° viewing angle, 10-mm outer diameter, 6-mm working channel, 125-mm working length and 13.7-mm outer diameter working cannula (iLESSYS Delta; Joimax, Karlsruhe, Germany) was used for contralateral lateral recess decompression. A 2-cm skin incision was made on the medial border of the facet joints at the target level. After serial dilation, the working cannula was inserted and docked at the spinolaminar junction of the ipsilateral side, and contralateral sublaminar drilling was performed to create a sublaminar space up to the contralateral medial part of the foramen. The thickened ligamentum flavum in the contralateral lateral recess and medial foraminal region were removed using endoscopic forceps. The contralateral S1 nerve root was decompressed, and the medial part of the facet joint was exposed.

Subsequently, we changed to a smaller diameter endoscope with a viewing angle of 30°, an outer diameter of 7.3 mm, a 4.7-mm working channel, and a total length of 251 mm (TESSYS; Joimax) to pass the narrow foraminal area (Video 1). The medial part of the SAP was drilled, and the foraminal ligamentum flavum was removed to expose the ENR and entire disc height (Figure 3A). The hypertrophied annulus and prominent bony

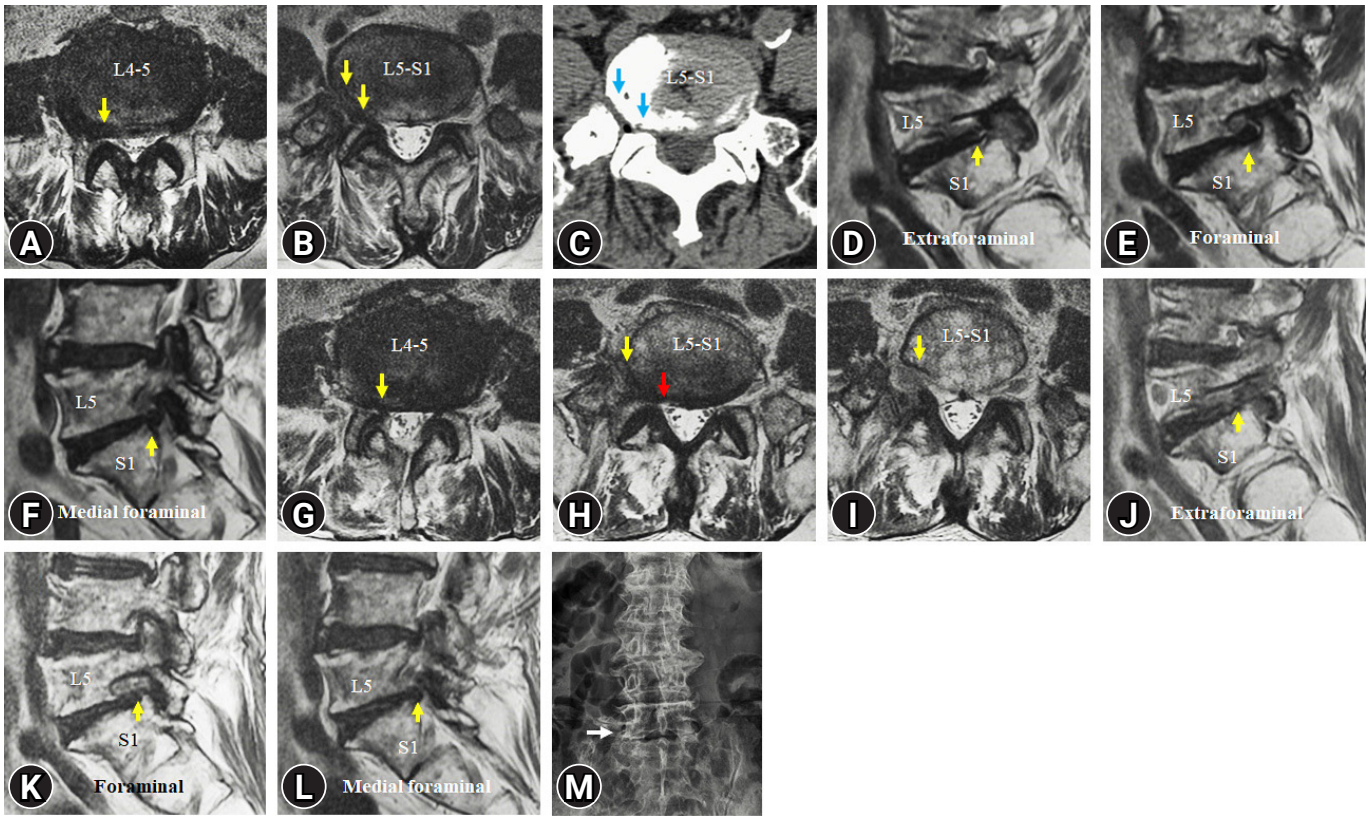

Figure 1. Pre and postoperative images for the initial operation at the L4-5 and L5-S1 levels. (A) Preoperative magnetic resonance imaging (MRI) shows lateral recess stenosis at the right L4-5 level. (B, C) Preoperative MRI and computed tomography images reveal foraminal, extraforaminal, and far-out stenosis at the right L5-S1 level. (D–F) Foraminal sagittal MRI documented the prominent bone spur and herniated disc in the foraminal and extraforaminal areas. (G–I) Lumbar endoscopic lateral recess decompression was performed for the L4-5 level, and transforaminal endoscopic lumbar foraminotomy was performed for the L5-S1 level using the full endoscopic system. Postoperative MRI axial images show lateral recess decompression at the right L4-5 level and foraminal-extraforaminal (yellow arrows) decompression at the right L5-S1 level. Medial foraminal stenosis was not resolved (red arrow). (J–L) Postoperative foraminal sagittal MRI reveals decompressed foraminal and extraforaminal areas (yellow arrows) by removing the dorsal foraminal lesions. However, bone spur and herniated disc at the ventral foraminal space have remained. (M) Lateral wedging is minimal on the postoperative X-ray image.

spur were removed using an endoscopic 3.0-mm diamond drill and forceps to expand the foraminal space and access the extraforaminal region (Figure 3B, C). After drilling the remaining overlying SAP (Figure 3D), a severely compressed ENR was found, entrapped by a prominent bony spur, hypertrophied annulus, and thick adhesion tissues (Figure 3E).

Decompression of the dorsal aspect of the foraminal-extraforaminal space is challenging because of severe perineural adhesions (Figure 3E). However, virgin tissue and perineural fat were maintained below ENR. Therefore, neural decompression focuses on ventral foraminal expansion along the virgin dissection plane between the ENR and ventral foraminal pathologies. The ventral foraminal bone spurs were removed using an endoscopic drill to create additional space for neural decompression and instrument access (Figure 3F). This free space decreases foraminal pressure and enables the identification of a dissection plane between the ENR and hypertrophied annulus. Subsequently, the secured herniated disc and calcified annulus were removed using forceps and a cutting rongeur (Figure 3G).

With the enlargement of the foramen, the endoscope was introduced deeper through the caudal-ventral foramen to explore extraforaminal and far-out lesions. The ENR starts to curve downward at the extraforaminal area and is squeezed by the SAP base part and a bone spur in this patient with a collapsed neuroforamen. Therefore, bone drilling should be extended to the SAP base and foraminal portion of the lower-level pedicle to release the extraforaminal part of the ENR. If neural decompression is insufficient, partial vertebrotomy can help secure extra space along the path of ENR. Subsequently, the endoscope was carefully advanced into the far-out area, where the ENR was pressed and distorted by the prominent bone spur. Detailed bone drilling is limited to the far-out area due to the

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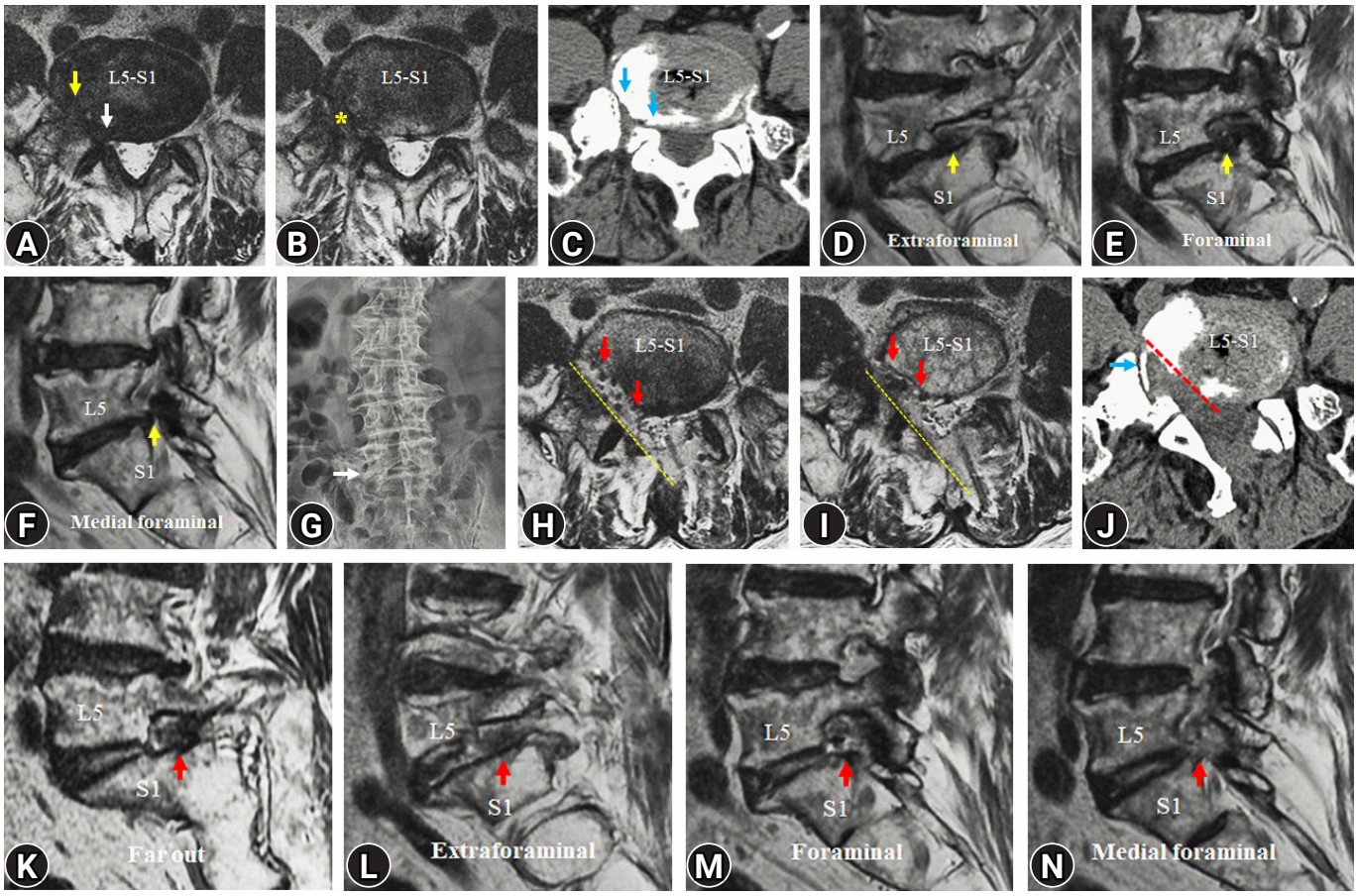

Figure 2. Pre and postoperative images for the revision surgery for the recurrent foraminal-extraforaminal stenosis at the right L5-S1 level. (A–C) Preoperative magnetic resonance imaging (MRI) and computed tomography (CT) images reveal severe stenosis of the foraminal, extraforaminal, and far-out areas (yellow arrow). The previous surgical tract (yellow asterisk) is unclear due to the restenosis. Bone spur in the ventral foraminal area has grown, inducing recurrent stenosis of the foraminal-extraforaminal area (blue arrows). Lateral recess stenosis has combined at the right L5-S1 level (white arrow). (D–F) Foraminal sagittal MRI shows recurrent stenosis without a perineural fat signal at the foraminal and extraforaminal areas. The exiting nerve root (ENR) is compressed by the bone spur and herniated disc (yellow arrows) and entrapped by the adhesion tissues. (G) Lateral wedging has not aggravated for 3 years after the initial foraminotomy on the X-ray image. We performed the full endoscopic interlaminar contralateral approach to resolve the contralateral lateral recess and recurrent foraminal-extraforaminal stenoses simultaneously through one surgical direction. (H, I) Postoperative MRI axial images reveal sufficiently decompressed lateral recess, foraminal, and extraforaminal area (red arrows) at the right L5-S1 level. The tract of the endoscopic approach is documented along with the sublaminar space and dorsal foraminal space (yellow dotted lines). (J) On the CT axial image, the ventral foraminal free area is created by bone spur removal and partial vertebrotomy (yellow dotted line) while preserving the facet joint. Some part of calcified adhesive tissue covering the nerve has remained at the far-out area (blue arrow). (K–N) On the sagittal foraminal MRI images, ventral foraminal pathologies are entirely removed, and remarkable neural decompression was obtained from the medial foraminal to the far-out areas (red arrows). Far-out stenosis is resolved by making the free space under the nerve root, and the natural downward course of the nerve root is restored (red arrow in K).

drill bit's long tract. Therefore, after thinning the bone spur, the remaining spur was removed using a cutting rongeur and forceps to expose the opening to the retroperitoneal area (Figure 3H). Finally, the ENR was entirely decompressed, and a natural downward path from the extraforaminal to far-out regions was restored (Figure 3H, I).

3. Result

Postoperatively, the motor weakness in the right leg improved from grade 4 to 4+. The radiating pain and neurogenic claudication in the right leg also improved remarkably. The patient experienced mechanical right buttock pain while straightening his back for two months after surgery, which was relieved with conservative treatment. Postoperative MRI and CT images

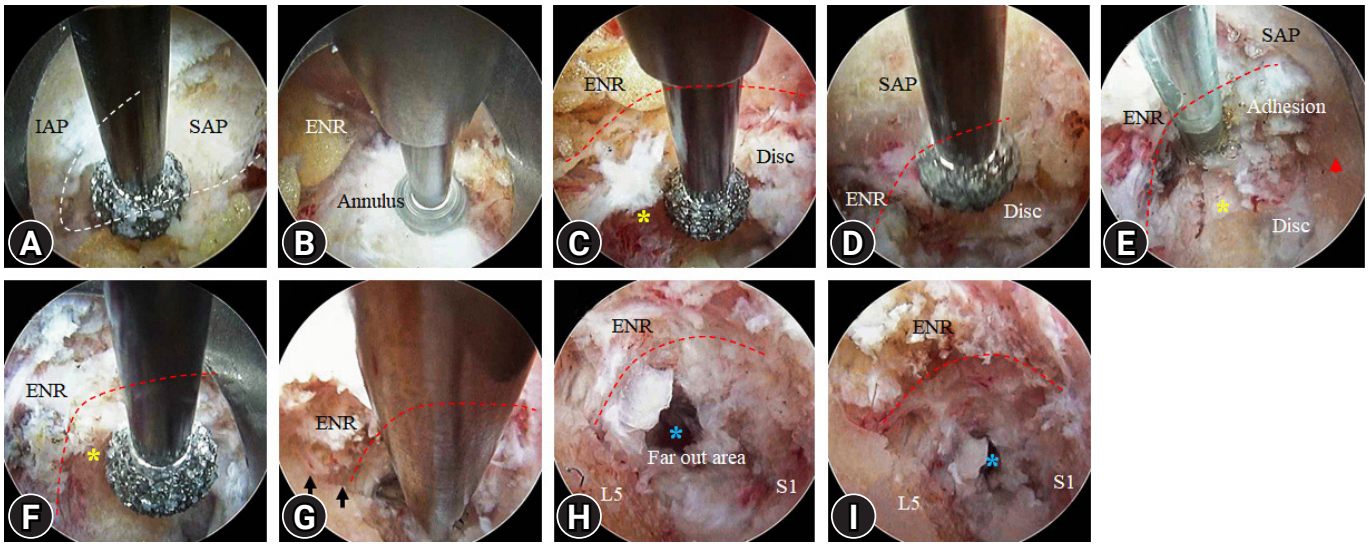

Figure 3. Intraoperative views of right-sided full endoscopic intralaminar contralateral approach for the recurrent contralateral foraminal-extraforaminal stenosis at the L5-S1 level. (A) Drilling the medial part of the superior articular process (SAP) to expose the foraminal space. (B) After identifying the exiting nerve root (ENR) and foraminal herniated disc, annulotomy was performed using the endoscopic drill. (C) Drilling of the prominent bone spur (yellow asterisk) and removal of the herniated disc. (D) Drilling of the SAP base part to open the extraforaminal space. (E) The ENR is entrapped by the adhesive tissue, bone spur, and herniated disc in the extraforaminal area. Partial vertebrotomy (red arrowhead) is necessary to expose the extraforaminal and far-out lesions. (F) Extraforaminal bone spur (yellow asterisk) was removed with an endoscopic drill to create sufficient space for instruments to access the far-out area. (G) The undersurface of the ENR (black arrows) is confirmed after removing the bone spur. Far-out residual bone spur and soft tissues are removed using the cutting rongeur. (H, I) After completing the far-out decompression, open space into the retroperitoneal space is exposed (blue asterisks). ENR restored its natural downward course without distortion.

showed sufficient decompression of the lateral recess and foraminal-extraforaminal areas (Figure 2H–J). The caudal and ventral portions of the foraminal-extraforaminal space were expanded by removing the bone spur and herniated discs. Far-out stenosis was also resolved with partial vertebrotomy (Figure 2K–N).

There were no recurrent symptoms of radiculopathy except for intermittent right buttock pain during the 12 months of follow-up. Preservation of the foraminal-extraforaminal expanded space was confirmed in the one-year follow-up MRI and CT images (Figure 4). Sufficiently expanded space created by drilling the SAP base and pedicle prevents restenosis and symptom recurrence (Figure 4D–G).

DISCUSSION

The paraspinal or transforaminal endoscopic approach is commonly used to treat lumbar foraminal and extraforaminal stenoses. In cases of severe osseous lumbar foraminal stenosis, sufficient bone spur removal at the ventral foraminal area can induce postoperative dysesthesia due to excessive retraction of the dorsal root ganglion during ventral foraminal decompression [4]. These difficulties are pronounced at the L5-S1 level because it has a high iliac crest, inclination of the disc space, and wide facet joints overlapping the disc space [3]. Therefore, bony spurs and calcified herniated discs occasionally remained during transforaminal endoscopic lumbar foraminotomy at the L5-S1 level. As the disc height decreases after foraminotomy, lateral recess stenosis is combined, and the remaining ventral foraminal pathologies can accelerate symptomatic foraminal restenosis. Furthermore, the growing syndesmophytes in the far-out area induce additional neural compression and distort ENR.

In this case of the L5-S1 level, fusion operation is usually performed to resolve the recurrent neural compression and combined lateral recess stenosis because revision foraminotomy can induce serious ENR injury, and excessive facet resection is necessary during the additional lateral recess decompression. However, fusion surgery is occasionally unsuitable for elderly patients with serious medical problems owing to invasive procedures. Alternative minimally invasive surgical approaches are necessary to achieve sufficient neural decompression in these patients. Fortunately, the newly advanced interlaminar contralateral endoscopic lumbar foraminotomy (ICELF) has shown a

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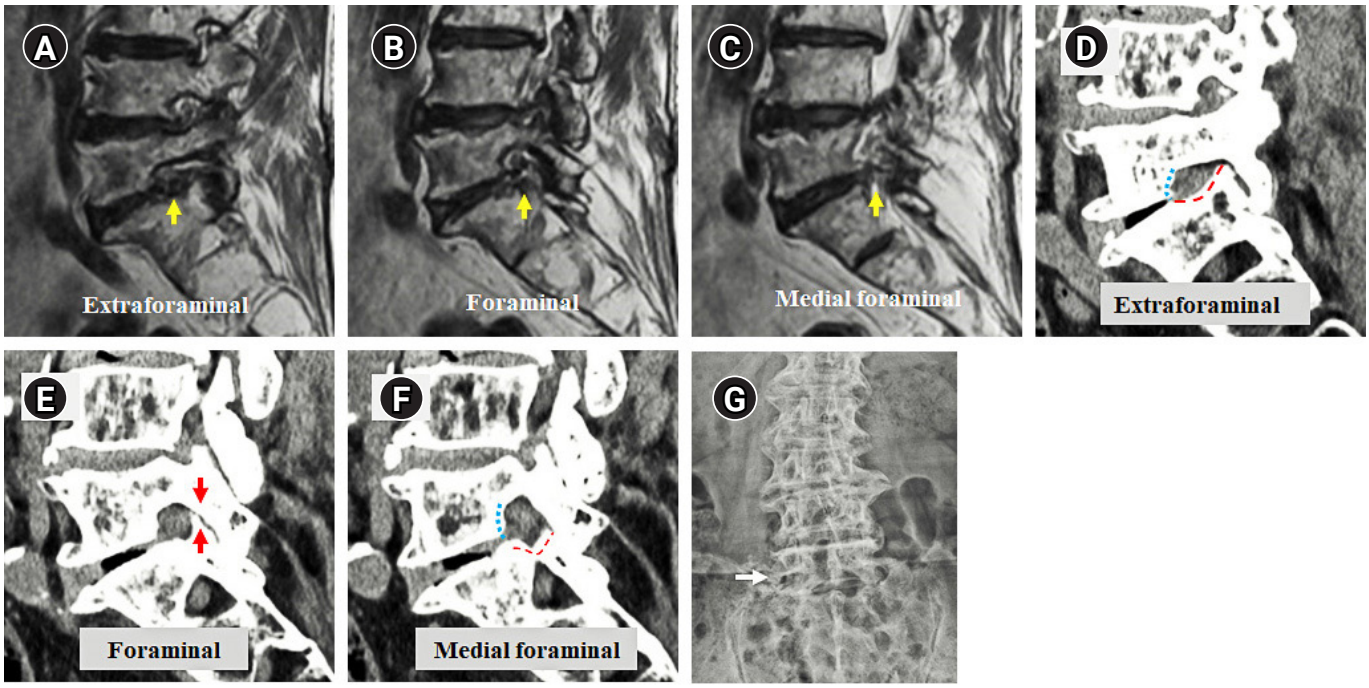

Figure 4. One-year follow-up images. (A–C) On the foraminal sagittal magnetic resonance imaging, expanded spaces in the foraminal and extraforaminal areas have well-maintained (yellow arrows). (D–F) A computed tomography image reveals well decompressed foraminal space after removing the bone spur (blue dotted line) and partial vertebrotomy (red dotted line). Propping structures prevent further foraminal height loss (red arrows). (G) Lateral wedging is not worsened in the X-ray image (white arrow).

favorable surgical outcome in treating contralateral coexisting lateral recess and foraminal-extraforaminal stenoses [2,3]. This technique is effective at all lumbar levels and more beneficial at the L5-S1 level with a wide facet joint, longer foraminal length, and inclination of the disc space [3,5]. Furthermore, several patients with recurrent foraminal stenosis have been successfully treated using the ICELF technique [4].

The dorsal aspect of the foraminal-extraforaminal area is full of severely adhesive tissues, and the ENR is entrapped by the hypertrophied SAP, prominent bone spur, and herniated disc from the caudal-ventral aspect. Revision surgery of the transforaminal approach through the previously operated tract can cause serious neural injury because of the unclear dissection plane between the ENR and adhesion tissues. Furthermore, excessive neural retraction is necessary to remove ventral foraminal lesions during the revision transforaminal endoscopic approach.

However, during ICELF, a small-diameter endoscope passes the collapsed neuroforamen through the caudal-ventral foraminal space while exploring the underlying ENR. Although severe adhesion tissues cover the dorsal aspect of the ENR, the virgin dissection plane with peridural fat is maintained at the ventral portion of the ENR. Therefore, ventral foraminal pathologies, including bone spurs and herniated discs, can be successfully removed along the virgin dissection plane without nerve root retraction. Sufficient free space is created under ENR, and this space enables adequate neural decompression and prevents restenosis even in the collapsed foramen.

The patient in this study had far-out stenosis caused by a growing syndesmophytes and hypertrophied ala bone. The ENR was compressed, and the downward course was distorted. Far-out stenosis had to be resolved for complete neural decompression. Therefore, extensive bone drilling was performed, including the syndesmophytes and cranial part of the S1 vertebrae, to create sufficient space under ENR. However, removing the ala bone from inside the neuroforamen is challenging. This free space resolved the far-out stenosis and played a role in preventing restenosis.

In the collapsed neuroforamen, the cranially migrated SAP contacts the upper-level pedicle or base part of the inferior articular process (IAP) and acts as a propping mechanism to prevent a further decrease in foraminal height. ICELF procedures do not remove the propping structures, such as the tip of the SAP and the caudal part of the isthmus or IAP. Instead, neural decompression was focused on the ventral foraminal-extraforaminal area, and sufficient additional spaces were obtained

by removing the bony spur and partial vertebrotomy. These mechanisms may cause delays in restenosis and lateral wedging. This patient did not experience a recurrence of L5 radiculopathy during a one-year follow-up. In addition, the expanded foraminal and extraforaminal spaces were well preserved, and lateral wedging did not progress in the one-year follow-up images (Figure 4). However, this propping mechanism may not prevent foraminal restenosis in cases with preserved disc height. As disc height decreases, restenosis worsens inevitably, even after ICELF is performed.

Another advantage of ICELF is the simultaneous treatment of combined lateral recess stenosis while minimizing facet violation. The outer facet joint capsule and covering soft tissues are not injured during ICELF because contralateral lateral recess stenosis is decompressed by obliquely undercutting the medial part of the facet joint while the endoscope passes through the sublaminar space. A preserved facet may help to prevent postoperative segmental instability. However, if ipsilateral medial fenestration is performed for lateral recess stenosis, excessive facet resection is unavoidable because the lateral facet is resected during the previous foraminotomy procedure.

For successful ICELF without complications, surgeons should have sufficient experience with endoscopic lumbar decompression for ipsilateral and contralateral spinal canal stenosis and the endoscopic transforaminal approach for foraminal stenosis. Extensive experience with ICELF is also essential to performing ICELF for restenosis, especially at the L5-S1 level. Radicular arterial bleeding obscures the endoscopic view and causes incomplete decompression and nerve root injuries. The tract of the radicular artery should be identified and coagulated using a radiofrequency (RF) probe before removing lesions close to the ENR. However, the aggressive use of RF probes can induce nerve root injury and postoperative dysesthesia. Hemostasis is very difficult if segmental arterial bleeding occurs in the far-out area beyond the endoscopic view, and uncontrolled bleeding can induce a retroperitoneal hematoma. Preventive coagulation of vessels using the RF probes is critical to prevent retroperitoneal arterial bleeding during far-out decompression. After opening the far-out space, saline infusion pressure should be reduced to prevent retroperitoneal fluid collection.

Although this technique has impressive advantages, revision ICELF surgery should only be an alternative surgical option in highly selected patients. If recurrent lumbar foraminal-extraforaminal stenosis is combined with lateral recess stenosis, fusion surgery should be performed first instead of ICELF, especially at the L5-S1 level. Furthermore, ICELF is not recommended if segmental instability is found on preoperative radiographic images.

CONCLUSION

We successfully treated recurrent foraminal-extraforaminal and combined lateral recess stenoses using the full endoscopic interlaminar contralateral approach at the L5-S1 level. The endoscopic system moves parallel to the ENR while ensuring sufficient free space below the ENR. This technique may be an alternative surgical method to treat the recurrent foraminal-extraforaminal stenosis in the L5-S1 neuroforamen collapse. However, technical ability and surgical experience can affect surgical outcomes and should be considered in highly selected patients unsuitable for fusion operations.

NOTES

Ethical statements

This study was approved by the institutional review board (approval No. 2202-W03).

Conflicts of interest

No potential conflict of interest relevant to this article.

Supplementary Materials

Supplementary Video 1. Left-sided full endoscopic interlaminar contralateral approach for the contralateral lateral recess stenosis and foraminal-extraforaminal restenosis. (https://doi.org/10.21182/jmisst.2022.00528.v001).

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Robotic-assisted Superior Gluteal Nerve Tumour Resection

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Sciatic notch tumours of the intra-pelvic variety are rare lesions and commonly arise from the sciatic nerve. These are usually benign neurogenic tumours and the most common of them is schwannoma. Conventional laparotomy techniques have associated surgical morbidity and significant blood loss. The advent of robotic systems and refinement in robotic-assisted surgical techniques to access deep lying pre-sacral lesions has offered a novel way to surgically handle such lesions thereby reducing morbidity, hospital stay and blood loss. Here we are presenting a case of non-discogenic sciatica which was attributed to superior gluteal nerve tumour and was surgically resected using robotic-assisted technique.

Key Words: Neurilemmoma, Sciatica, Neoplasms, Sciatic Nerve

INTRODUCTION

The evolution of robotic-assisted surgery has been a boon to minimally invasive surgery. Since the first use of robotics based on laparoscopic principles in cardiothoracic surgery [1], many other specialities have taken the advantage of robotic systems. It has made surgically difficult cases more accessible and with less damage to the surrounding tissues.

Primary tumours of the superior gluteal nerve are unheard of Pre-sacral and sciatic notch tumours are uncommon cause of non-discogenic sciatic pain in the adult population and usually arise from the sciatic nerve [2]. Schwannomas are the commonest benign tumours in this anatomical location [3].

CASE REPORT

A 64-year-old lady presented with chief complaints of right buttock and radiating leg pain of one month duration. There was no history of injury or any other significant precipitating factor. The pain was insidious in onset, progressive, radiating, severe with paroxysmal severe pain (VAS 7–8). The pain distribution was along the S1 dermatome. There was no history of claudication and sensory loss or motor weakness. Bowel and bladder habits of the patient were normal.

Patient has a past medical history of hypertension, angina and hypothyroidism for which she is on medication. She has a past surgical history of hysterectomy 20 yours ago and L4–5 spine stabilisation in 2009. There is no other significant contributory medical history.

On clinical examination, the only finding was right buttock and posterior thigh paresthesia corresponding to S1 dermatome. Straight leg raising (SLR) test was negative. There was no sensory or motor deficit. DTR were normal. The patient was evaluated with standard pelvis radiographs (Figure 1), CT scan (Figure 2) and MRI scan (Figure 3) which revealed a mass in the right superior gluteal nerve.

Except L4–5 level pedicle stabilisation implants no other feature was visible on plain radiographs.

CT scan images showed non-specific features of the mass, no bony lesion and contrast enhancement. MRI scan showed a 2.4 cm lesion, isointense on T1 imaging and hyperintense on T2 imaging and contrast enhancement, suggesting a neurogenic tumour arising from the right superior gluteal nerve. The symptoms were most probably due to pressure effect on the sciatic nerve at the sciatic notch.

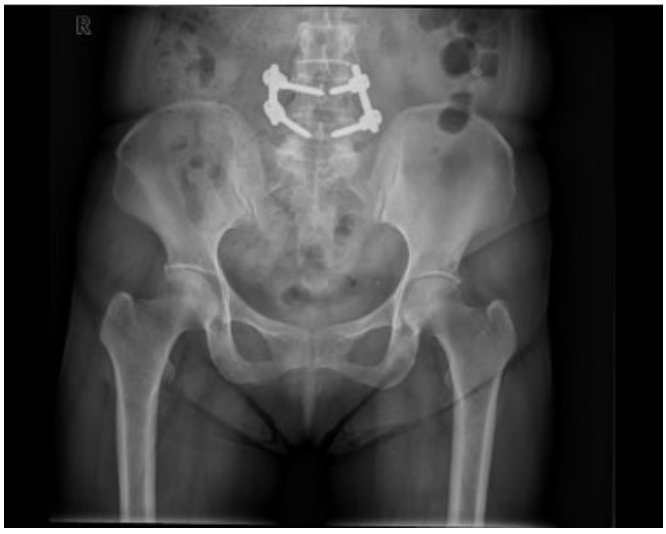

Figure 1. Plain radiograph: L4–5 level reveals metal implants for posterior stabilization.

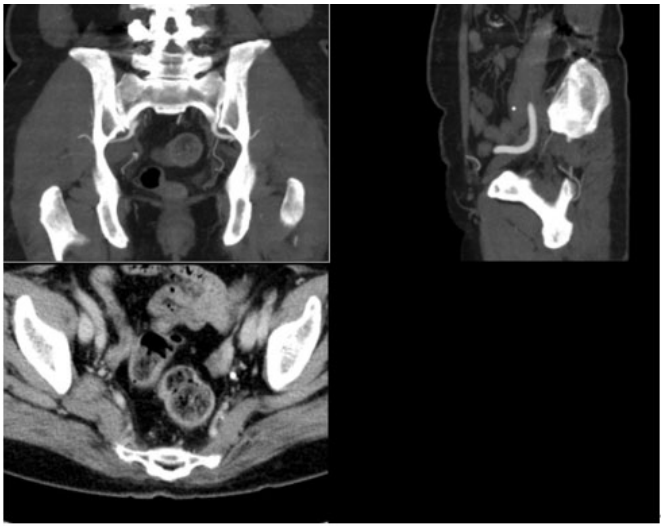

Figure 2. CT scan: Non-specific features of a mass lesion. No bony erosion.

1. Surgical Technique

The patient underwent pre-operative evaluation for surgical fitness.

Patient was operated under general anaesthesia with endotracheal intubation in supine lithotomy position (Allen chair). Foleys urinary catheter and rectal tube were inserted.

Patient was prepared, painted and sterile draping was done. Operated with Da Vinci Xi System. Total six surgical ports including 4 for robotic arms were used.

A small incision was made just below the umbilicus, CO_2 gas is inflated up to 15 mmHg pressure to create pneumoperitoneum. Additional ports were made. After ruling out intestinal injury, the robotic system was docked. Trans-peritoneal route was used to approach right side retroperitoneal pre-sacral space close to the intra-pelvic portion of the sacral nerves close to the right internal iliac artery. Meticulous dissection was done, smaller vessels were cauterized and bisected. Tumour approached, resected and collected in retrieval bag (Supplementary Video; which demonstrates the procedure of surgery). Peritoneum closed in layers over drain. Scarring due to previous hysterectomy did not create any difficulty in surgical dissection.

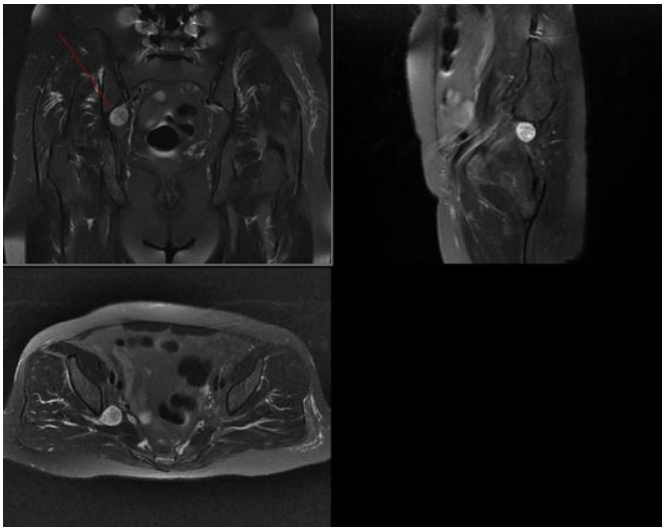

Figure 3. MRI scan: 2.4 cm lesion, isointense on T1 hyperintense on T2 and contrast enhancement, arising from the right superior gluteal nerve.

Total blood loss of approximately 50 mL.
Duration of anesthesia: 170 minutes.
Duration of surgery: 135 minutes.

2. Histopathology Report

An irregularly shaped pale brown tissue specimen measuring 2.2×2.1×1.6 cm. Micr oscopic examination confirmed as schwannoma (Figure 4).

3. Postoperative Scans

Postoperative MRI scan (Figure 5) showed resection of the mass and minimal fluid collection.

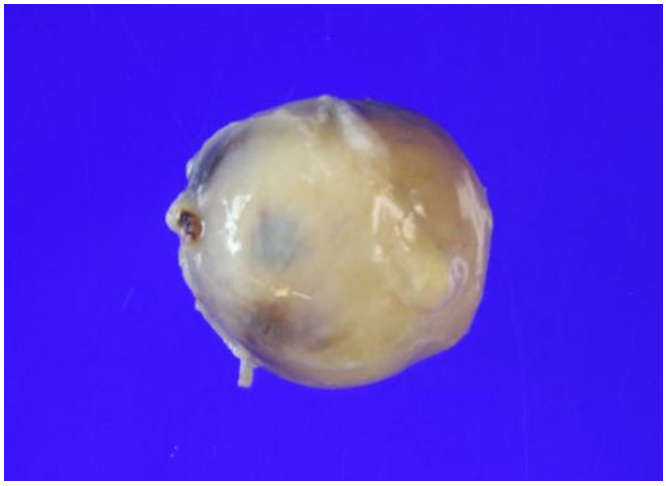

Figure 4. Gross features of the excised tumour mass.

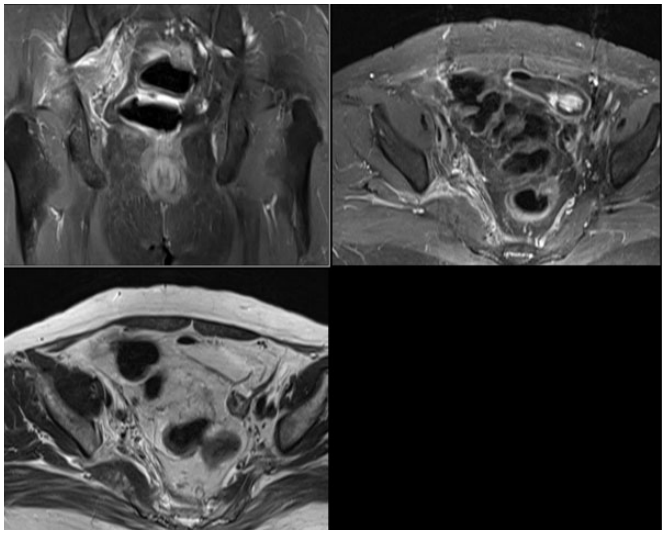

Figure 5. Post op MRI scan: Complete resection of mass.

4. Postoperative Patient Status

Patient was relieved of her symptoms postoperatively.

5. Review of Literature

The da Vinci surgical system was launched in 2014 as an improved version to da Vinci Si surgical system. It is currently in its 4th generation and is the most commonly used system for robotic-assisted laparoscopic surgery [4,5]. The da Vinci Xi Surgical system had improved features as compared to the previous generation machine with improved robotic arms, camera docking, longer instruments, new vision architecture and various other enhanced upgradations [4,6,7].

The superior gluteal nerve arises from the sacral plexus from the ventral divisions of L4, L5, and S1. It forms within the pelvis and exits through the greater sciatic notch superior to the piriformis muscle (suprapiriformis foramina) and divides into superior and inferior branches. It is a pure motor nerve. The superior gluteal nerve is accompanied by the superior gluteal vessels. This complex has an intrapelvic and an extra-pelvic course. The superior gluteal artery is the largest branch of the internal iliac artery whereas the superior gluteal veins are the venae comitantes to this artery [8,9].

Peripheral nerve root tumours are rare lesions with an estimated incidence of 1 in 100,000 [10]. Most common of these are benign schwannomas which are slow growing tumours [11]. 13.5% of peripheral schwannomas are reported in the lower limbs with sciatic nerve accounting for one percent cases. These tumours being slow growing have a thick capsule and hence complete surgical resection is possible and is the treatment of choice [12]. Schwannoma or neurinoma or neurilemmoma is a benign peripheral nerve tumour arising from Schwann's cells [2]. These are the most common nerve root tumours. They occur in the age group of 30 to 50 years, with no specific gender predisposition. They may be solitary or multiple. Malignant transformation is rare. Sciatic notch schwannomas can be intra-pelvic, extra-pelvic or mixed type [3].

DISCUSSION

Sciatic notch tumours of the extra-pelvic type are approached through the infra-gluteal approach [13] or trans-gluteal approach [14], those of intra-pelvic type need a trans-abdominal approach [15] and dumbbell shaped lesions across traversing across the sciatic notch require a combined approach [14-16]. Reports of intra-pelvic lesions resected by the infra-gluteal

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approach [3] and extra-pelvic lesions resected using tubular retractor [12] have also been described.

The case presented here is purely intra-pelvic type. Tumours arising from the sciatic nerve or its branches near the sciatic notch have been described in the literature earlier [2,3,12,14,15]. One case arising from the pudendal nerve has been mentioned [17,18]. However, to our knowledge no case has been reported arising from the superior gluteal nerve.

Conventional trans-peritoneal or retro-peritoneal approach for intra-pelvic and dumbbell shaped lesions through a midline laparotomy cause significant surgical trauma and associated with complications related to the alimentary system, urinary system and encounters major blood vessels and nerves in the surgical field [3]. These procedures are associated with increased surgical time, high blood loss, increased stay in hospital and significant morbidity and mortality [14]. This approach is unavoidable in cases of large sized tumours, malignancies with or without surrounding infiltration, and in cases where lymph nodes involvement must be assessed or addressed. However, in benign lesions with relatively small size, the morbidity and mortality associated with the traditional approach are more problematic as compared to the symptoms.

Laparoscopic approach to pre-sacral tumours are also described but difficulty in visualisation, limited field of vision, restricted field for instruments and high complication rate make it a cumbersome approach [19,20].

In general, treatment for benign tours is en-bloc resection. However, radiosurgery can be performed when it is difficult to completely remove with surgical treatment or when there are many major structures around the tumour, so there is a high possibility of blood loss or nerve injury during surgery. If complications can be minimized and the tumours can be completely removed, surgical treatment is better than radiosurgery.

So, robotic-assisted technique provide a safe surgical option for resection of such benign tumours reducing the surgical time, blood loss and minimising the associated morbidity and mortality [21,22].

The price and installation of these systems, maintenance cost, training investment and reproducibility of good results with challenging surgical cases remains a major limiting factor in the use of these hi-tech surgical gadgets. Also, the availability of these systems is restricted to large multi-speciality centres.

CONCLUSION

Robotic-assisted nerve root tumour excision in the sciatic notch, especially of the intra-pelvic and mixed type, is an effective way for reducing surgical morbidity and blood loss as compared to conventional laparotomy techniques.

NOTES

Ethical statements

This study has been approved by the institutional review board of Seoul Saint Mary's Hospital, Catholic university of Korea (KC22ZISI0296).

Conflicts of interest

No potential conflict of interest relevant to this article.

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