

Laboratory Investigation

Comparison of SpineJet™ XL and Conventional Instrumentation for Disk Space Preparation in Unilateral Transforaminal Lumbar Interbody Fusion

Han-Yong Huh, M.D.,¹ Cheol Ji, M.D.,¹ Kyeong-Sik Ryu, M.D.,² Chun-Kun Park, M.D.²

Department of Neurosurgery,¹ St. Paul's Hospital, The Catholic University of Korea, Seoul, Korea

Department of Neurosurgery,² Seoul St. Mary's Hospital, The Catholic University of Korea, Seoul, Korea

Objective : Although unilateral transforaminal lumbar interbody fusion (TLIF) is widely used because of its benefits, it does have some technical limitations. Removal of disk material and endplate cartilage is difficult, but essential, for proper fusion in unilateral surgery, leading to debate regarding the surgery's limitations in removing the disk material on the contralateral side. Therefore, authors have conducted a randomized, comparative cadaver study in order to evaluate the efficiency of the surgery when using conventional instruments in the preparation of the disk space and when using the recently developed high-pressure water jet system, SpineJet™ XL.

Methods : Two spine surgeons performed discectomies and disk preparations for TLIF in 20 lumbar disks. All cadaver/surgeon/level allocations for preparation using the SpineJet™ XL (HydroCision Inc., Boston, MA, USA) or conventional tools were randomized. All assessments were performed by an independent spine surgeon who was unaware of the randomizations. The authors measured the areas (cm²) and calculated the proportion (%) of the disk surfaces. The duration of the disk preparation and number of instrument insertions and withdrawals required to complete the disk preparation were recorded for all procedures.

Results : The proportion of the area of removed disk tissue versus that of potentially removable disk tissue, the proportion of the area of removed endplate cartilage, and the area of removed disk tissue in the contralateral posterior portion showed $74.5 \pm 17.2\%$, $18.5 \pm 12.03\%$, and $67.55 \pm 16.10\%$, respectively, when the SpineJet™ XL was used, and $52.6 \pm 16.9\%$, $22.8 \pm 17.84\%$, and $51.64 \pm 19.63\%$, respectively, when conventional instrumentations were used. The results also showed that when the SpineJet™ XL was used, the proportion of the area of removed disk tissue versus that of potentially removable disk tissue and the area of removed disk tissue in the contralateral posterior portion were statistically significantly high ($p < 0.001$, $p < 0.05$, respectively). Also, compared to conventional instrumentations, the duration required to complete disk space preparation was shorter, and the frequency of instrument use and the numbers of insertions/withdrawals were lower when the SpineJet™ XL was used.

Conclusion : The present study demonstrates that hydrosurgery using the SpineJet™ XL unit allows for the preparation of a greater portion of disk space and that it is less traumatic and allows for more precise endplate preparation without damage to the bony endplate. Furthermore, the SpineJet™ XL appears to provide tangible benefits in terms of disk space preparation for graft placement, particularly when using the unilateral TLIF approach.

KEY WORDS : Transforaminal lumbar interbody fusion · Discectomy.

INTRODUCTION

The most important goal of interbody fusion surgery in the lumbar spine is to achieve a solid and stable arthrodesis

that can sustain loads while maintaining adequate disk height¹⁵. To ensure solid and stable fusion, it is essential to remove the nucleus pulposus and vertebral endplate cartilage from the disk space without damaging the endplate.

Transforaminal lumbar interbody fusion (TLIF) was introduced⁶ in the early 1980s and became popular. However, until now, surgeons experienced technical difficulties when performing unilateral TLIF using conventional instrumentation. Such technical limitations included insufficient removal of the disk and endplate cartilage, risk of damage

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• Address for reprints : Chun-Kun Park, M.D.

Department of Neurosurgery, Seoul St. Mary's Hospital, The Catholic University of Korea, 505 Banpo-dong, Seocho-gu, Seoul 137-040, Korea
Tel : +82-2-2258-6122, Fax : +82-2-594-4248

E-mail : ckpmd@catholic.ac.kr

to major surrounding vascular or neural structure because of repeated instrumentation use, and prolonged surgical time.

Recently, a new high-pressure water jet system (SpineJet™ XL, HydroCision, Inc., Boston, MA, USA) was introduced¹⁸⁾. The unit has a slender design and several angled working channels, and it is reported to be beneficial in terms of a less traumatic and more efficient disk preparation, particularly in the contralateral portion of the disk space.

Therefore, the author has conducted a randomized, comparative cadaver study to evaluate the efficiency of the surgery when using conventional instruments in the preparation of the disk space and when using the recently developed high-pressure water jet system.

MATERIALS AND METHODS

Study design and groups

This cadaver study (using four cadavers) designed for two surgeons would have equal exposure to both the SpineJet™ XL and conventional instruments. Each surgeon performed a procedure at L1/L2, L2/L3, L3/L4, L4/L5, and L5/S1 using both instruments. The average age was 60.3 ± 12.5 years (range : 42-76). The medical history of the specimens was checked to exclude those with infection, severe trauma and previous surgery in the lumbar spine.

To achieve the above exposure of the two surgeons, the following method was used. The vertebral levels were designated as L1/L2, L2/L3, L3/L4, L4/L5, and L5/S1, and the techniques were designated as conventional instruments = C and SpineJet™ XL = SJ. The surgeons were identified as #1 and #2. A coin flip determined the technique for levels L1/L2 for each instrument (C or SJ). Subsequent levels in the two cadavers were subjected to the techniques in alternating sequence. Small slips of paper, marked with either surgeon #1 or surgeon #2, were placed in a box and drawn to determine which surgeon would operate at each level (starting at L1/L2, followed by L2/L3, L3/L4, etc.). This procedure was inverted for the third cadaver; that is, the

surgeons operated on levels not operated on with the first cadaver. For the second and fourth cadavers the whole process was repeated by re-drawing slips of paper. Table 1 provides the details of the cadaver/surgeon/level allocations.

The surgeons had only been familiar previously with the use of conventional instruments. The surgeons familiarized themselves with the SpineJet™ XL technique for about

four hours before commencing this study.

Surgical techniques

To standardize the evaluation, the lumbar spines were exposed through a left-sided unilateral paramedian approach. After osteotomy of the inferior articular process of the upper vertebral body, the facet joint was resected. After incising the posterolateral fibrous annulus with a #11-blade, disk nucleus removal and endplate cartilage preparation for fusion were performed using either conventional instruments or the SpineJet™ XL unit. After removing as much disk material as possible (to the extent that the surgeon involved was willing to complete a unilateral TLIF), the next randomized assigned disk level was approached. All intraoperative data, including the duration of the entire procedure and the number of insertions and withdrawals of the instruments required to complete disk preparation, were recorded by an independent spine surgeon during the procedures.

Instruments

Conventional instruments : The conventional surgical instruments used were generic standard hand instruments for intervertebral disk space preparation (straight and curved curettes, Kerrison punches and shavers, and pituitary forceps of various sizes).

SpineJet™ XL : The SpineJet™ XL harnesses power water and venturi suction effect to safely and precisely cut and evacuate tissue within the disk space. The SpineJet™ XL system contains four basic components : a disposable quick connector, a disposable handpiece (SpineJet 20° XLS, 75° XLS) (Fig. 1), a power console, and a foot switch. The quick connector consists of the connector itself, a pump cartridge, and hoses.

The pump cartridge is mounted on the user interface which is located on the front of the power console (this connection provides power to the disposable handpiece). The foot switch allows remote actuation of the power console. The system is designed to work with any disposable hand-

Table 1. Distribution of techniques, surgeons, levels of operation, and cadavers

Cadaver	Level	Method	Surgeon	Cadaver	Level	Method	Surgeon
1	L1/L2	C	1	3	L1/L2	C	2
1	L2/L3	SJ	2	3	L2/L3	SJ	1
1	L3/L4	C	2	3	L3/L4	C	1
1	L4/L5	SJ	1	3	L4/L5	SJ	2
1	L5/S1	C	1	3	L5/S1	C	2
2	L1/L2	SJ	2	4	L1/L2	SJ	1
2	L2/L3	C	2	4	L2/L3	C	1
2	L3/L4	SJ	1	4	L3/L4	SJ	2
2	L4/L5	C	1	4	L4/L5	C	2
2	L5/S1	SJ	2	4	L5/S1	SJ	1

C : conventional instrumentation, SJ : SpineJet™ XL

piece. The power console pressurizes sterile water (pressure is user-controlled from approximately 1,200 to 15,000 pounds per square inch) that is supplied from a standard 3L irrigant supply bag. The pressurized water is pumped to the disposable handpiece and then exits the distal tip of the handpiece as a high-velocity jet, which crosses a short gap and is collected in an evacuation tube. Tissue directed into the gap is excised and drawn into the evacuation tube along with the water jet. The evacuation tube is connected to a standard waste container. Disposable handpiece distal tips may be configured to incorporate different cutting features (Fig. 2). The most efficient preparation of the disk space for interbody fusion using the SpineJet™ XL follows a three-step process : First, the nucleus pulposus is evacuated. Second, the annulus is thinned; this is accomplished using a windshield wiper motion to scrape the heel and toe of the handpiece along the inner surface of the annulus. Third, the endplates are scraped clean, completing the disk preparation. The lateral cutting sides of the handpiece are used to clean the cartilage in order to increase the surface area for interbody lumbar fusion (Fig. 3).

Imaging

After completing the surgical procedures, each disk level was prepared for image analysis. Spines were disarticulated, disks were axially sectioned at the level of the endplates, and the endplates were digitally photographed (Fig. 4).

Actual and available surface discectomy areas and endplate preparations of each disk were performed using Scion Image Analysis software (Scion Co., Frederick, MD, USA). Nine-section grids (3 × 3) were superimposed on the endplates to enable the assessment of the disk space sectors, as described by Javernick et al.⁹⁾

Analysis

The effectiveness of the discectomies and endplate preparations using conventional tools and the SpineJet™ XL were evaluated in terms of the completeness of disk preparation and the preparing difficulty in accessing disk portions (e.g., the contralateral region). This author measured the areas (cm²) and calculated the proportions (%) of the fol-



Fig. 1. The various types of disposable handpiece. In present study, 20° and 75° angled straight-shaft handpieces were used.

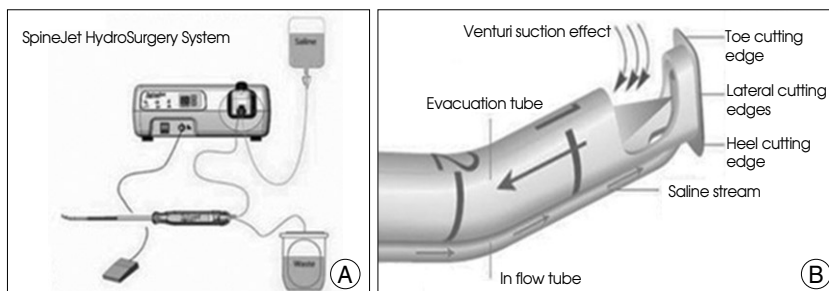


Fig. 2. The composition of SpineJet™ XL (HydroCision Inc., Boston, MA, USA) unit. A : Layout of the SpineJet™ XL system : the disposable quick connector, the disposable handpiece, the power console, and the foot switch. B : Diagram of the distal tip of the disposable handpiece.

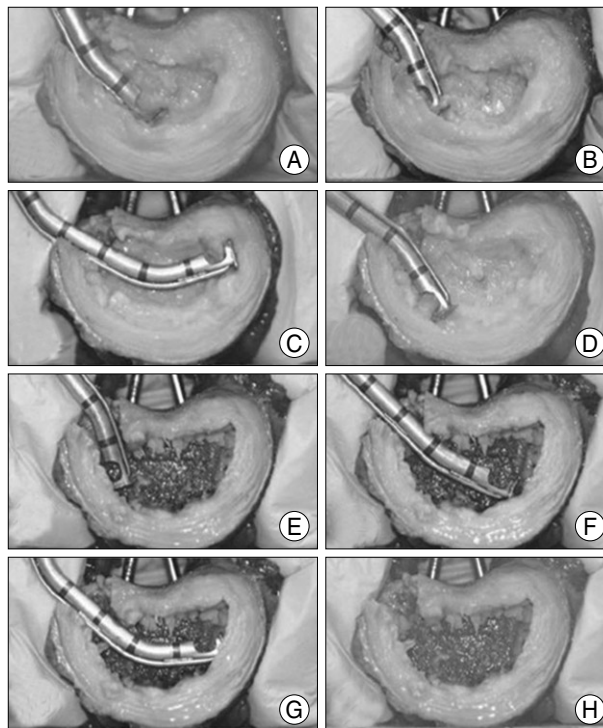


Fig. 3. Three-step process of disk space preparation using SpineJet™ XL (HydroCision Inc., Boston, MA, USA). A and B : First step, nucleus pulposus removal. C and D : Second step, annular thinning. E-H : Third step, endplate cartilage removal and completion of disk preparation.

lowing disk surfaces : 1) the overall disk cross sectional areas; 2) the potentially removable disk areas (ideal preparation area) (60% of area of the overall disk cross-sectional areas); 3) the proportion of the area of removed disk tissue versus that of potentially removable disk tissue, including the contralateral portion; 4) the proportion of endplate cartilage area removed; and 5) the proportion of endplate area damage. In addition, the duration of entire disk preparation and the number of instrument insertions and withdrawals required to complete the disk preparation were also recorded for all disk procedures. All assessments and measurements were performed by an independent spine surgeon who was unaware of the randomization details. Because the same specimen was used for each of the measured values, paired t-test was used to identify statistically significant differences. *p*-values of < 0.05 were considered statistically significant.

RESULTS

Areas of soft tissue and endplate cartilage removal

The mean overall disk cross sectional area was 22.30 ± 3.62 cm², and the mean cross sectional area of potentially removable disks was 13.38 ± 2.17 cm². The mean cross sectional areas of the disk tissues removed using the SpineJet™ XL and conventional instruments were 9.38 ± 3.32 cm² and 7.47 ± 2.23 cm², respectively. The mean cross-sectional areas of endplate cartilages removed using the SpineJet™ XL and conventional instruments were 2.18 ± 1.43 cm² and 3.18 ± 2.43 cm², respectively.

A total of 74.5 ± 17.2% potentially removable disk tissue was removed using the SpineJet™ XL and 52.6 ± 16.9% was removed using conventional instruments (*p* < 0.001). With regard to endplate cartilage removal, 18.5 ± 12.03% was removed using the SpineJet™ XL and 22.8 ± 17.84% was removed using conventional tools (*p* = 0.37) (Table 2).

Regarding the removal of tissue in the contralateral posterior portion, 67.55 ± 16.10% of potentially removable

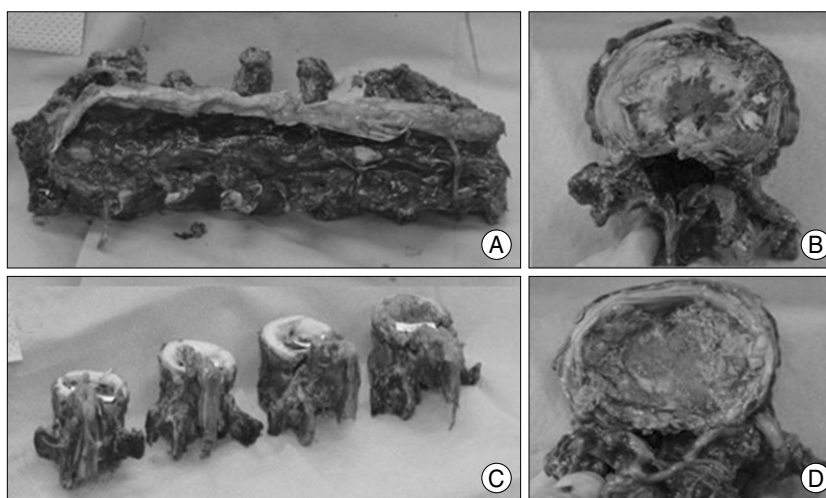


Fig. 4. Photographs of disk preparation performed in the study. A and B : After completing disk preparation, spines are disarticulated and the disks are axially sectioned at the level of endplates. The endplates are digitally photographed. C : Endplate preparation using conventional instruments. D : Endplate preparation using SpineJet™ XL.

Table 2. Areas of soft tissue and endplate cartilage removed

	Method	Mean overall cross sectional area (cm ²)	Calculated proportion (%)	<i>p</i> -value
All disk		22.30 ± 3.62		
Potentially removable (imaginary area)		13.38 ± 2.17	100	
Soft tissue removal	SpineJet™ XL	9.38 ± 3.32	74.5 ± 17.2	<i>p</i> < 0.001
	Conventional	7.47 ± 2.23	52.6 ± 16.9	
Endplate cartilage removal	SpineJet™ XL	2.18 ± 1.43	18.5 ± 12.03	<i>p</i> = 0.372
	Conventional	3.18 ± 2.43	22.8 ± 17.84	

Table 3. Results of disk removal in the contralateral portion of the disk space

	Method	Calculated proportion (%)	<i>p</i> -value
Soft tissue removal	SpineJet™ XL	67.55 ± 16.10	<i>p</i> < 0.05
	Conventional	51.64 ± 19.63	
Endplate cartilage removal	SpineJet™ XL	23.4 ± 9.95	<i>p</i> = 0.65
	Conventional	21.4 ± 16.50	

disk tissue was removed using the SpineJet™ XL, whereas 51.64 ± 19.63% was removed using conventional instruments (*p* < 0.05); 23.4 ± 9.95% of endplate cartilage was removed using the SpineJet™ XL, and 21.4 ± 16.50% was removed using conventional instruments (*p* = 0.65) (Table 3).

Area of the endplate damage

The mean cross sectional areas of endplate damage were 0.40 ± 0.69 cm² and 1.11 ± 1.36 cm² for the SpineJet™ XL and conventional instruments, respectively. With regard to endplate damage, mean damage was significantly less for the SpineJet™ XL than for conventional instruments (3.2 ± 5.18% vs. 8.0 ± 10.12%, respectively : *p* < 0.05) (Table 4).

In terms of damage to the endplates in the contralateral

posterior portion, $1.60 \pm 2.05\%$ of potentially removable disk tissue was removed using the SpineJet™ XL and $5.95 \pm 9.93\%$ was removed using conventional instruments ($p < 0.05$) (Table 4).

Number of instrument insertions and withdrawals

The number of manual insertions/ withdrawals was significantly less for the SpineJet™ XL (20.4 ± 15.4 vs. 69.7 ± 36.7 : $p = 0.002$) (Table 5).

Durations of entire disk preparation

Disk preparation took tended to be faster for the SpineJet™ XL (12 minutes, 58 seconds \pm 12 minutes, 39 seconds vs. 14 minutes, 41 seconds \pm 9 minutes, 43 seconds : $p = 0.739$) (Table 6).

Difference between surgeons

No significant differences were observed between the two surgeons in terms of the proportion of soft tissue and endplate cartilage removed, endplate damage, and number of instrument insertions and withdrawals. However, a significant difference in the mean time for entire disk preparation for conventional instruments was observed (10 minutes, 49 seconds \pm 5 minutes, 58 seconds vs. 17 minutes, 50 seconds \pm 12 minutes, 56 seconds : $p < 0.05$).

DISCUSSION

The biomechanical and biological successes of lumbar interbody fusion surgery depend on various factors such as the ability to prepare the disk space safely, the cellular environment in the disk space, the structural interbody support afforded for load transmission until the bones mature suffi-

ciently to carry the load, and the restoration of lumbar lordosis^{10,13,16}. Of these, discectomy and disk space preparation are the first steps toward achieving successful interbody arthrodesis. Lumbar interbody fusion surgery is usually performed using a posterior approach and a variety of fusion techniques (e.g., onlay interlaminar fusion, intertransverse process fusion, far lateral fusion, posterior lumbar interbody fusion)^{3,4}. However, these techniques have different success rates^{21,22}.

Since the introduction and propagation of the TLIF approach as an alternative to the PLIF and ALIF techniques in the early 1980s by Harms and Rolinger⁶ and Blume¹, the procedure has grown in popularity because it has many advantages^{7,14,23}.

Although various lumbar interbody fusion methods have been introduced, a standard on how much disk and endplate cartilage should be removed to ensure firm fusion has not yet been established, particularly in unilateral TLIF. Cloward² introduced the PLIF procedure in 1945. They claimed that almost the entire disk should be removed in the adjacent disk surfaces to be completely free from surrounding soft tissue, emphasizing that as much of the disk as possible should be removed and that the approach should be as close as possible to the anterior longitudinal ligament. In spite of this claim, some reports indicate that in actual practice, only 80-90% of the posterior disk space is removed during total discectomy¹¹.

Conventional TLIF has been shown to reduce complications; clinical studies with follow-ups between 12 and 64 months have found that fusion rates for TLIF are similar to those expected for other interbody fusion techniques-that is, more than 90%^{5,8,12,14,20}. However, the major criticism of unilateral TLIF procedures is that unilateral discectomy reduces the probability of fusion because of the limitations imposed by using conventional tools and because it is more difficult to remove sufficient disk material during discectomy and endplate preparation than during PLIF, especially from the contralateral posterior side using a unilateral approach. Sukovich et al.¹⁸ reported that most residual disk material was located in the contralateral posterior quadrant of the disk space. Javernick et al.⁹ also recommended a bilateral approach for some implants in order to avoid possible contralateral neural compromise due to retro-pulsed disk material after graft or implant insertion. Addi-

Table 4. Areas of damaged endplate

	Method	Calculated proportion (%)	p-value
Total disk area	SpineJet™ XL	3.2 \pm 5.18	$p < 0.05$
	Conventional	8.0 \pm 10.12	
Contralateral disk area	SpineJet™ XL	1.6 \pm 2.05	$p < 0.05$
	Conventional	5.9 \pm 9.93	

Table 5. Frequencies of instrument insertions/withdrawals

Method	Manual insertion / Withdrawals of instrument	p-value
SpineJet™ XL	20.4 \pm 15.4	$p < 0.05$
Conventional	69.7 \pm 36.7	

Table 6. Times required for entire disk preparation

Method	The duration of disk preparation	p-value
SpineJet™ XL	12 minutes, 58 seconds \pm 12 minutes 39 seconds	$p = 0.739$
Conventional	14 minutes, 41 seconds \pm 9 minutes 43 seconds	

tionally, when conventional instruments were used, the lateral and anterolateral disk space on the ipsilateral side also tended to contain residual disk material. On the other hand, overaggressive endplate cartilage removal can result in perforation and excavation of the bony endplate, and the contralateral anterior annulus is most at risk of being perforated by conventional instruments.

Recent reports have suggested that the majority of surgeons probably overestimate the thoroughness of discectomy and endplate preparation performed using conventional instrumentation¹⁴. Javernick et al.⁹ recently concluded that disk removal through a unilateral TLIF approach removed 69% of the available 80% surface area, which was only 56% of the disk. Sukovich et al.¹⁸ reported that the overall endplate surface area percentage exposed using the TLIF approach was 60% (range : 48.8-72.6%) of the total available end plate surface area. Similar results have also been reported^{17,19}.

Furthermore, the conventional instruments currently used during TLIF require multiple passes into and out of the disk space, which places vascular and neural structures at risk and extends operation times. Conventional instruments also require a significant amount of mechanical force, which places the endplate at risk of damage, particularly in the osteoporotic elderly.

In the present study, authors used a new high-pressure water jet system (SpineJet™ XL) to prepare disk spaces during unilateral TLIF, and compared the results quantitatively and qualitatively with those obtained using conventional instruments. We presumed that the area of potentially removable disk-the ideal preparation area-was 60% of the overall disk area¹⁸.

In our study, conventional instruments allowed for the removal of a mean $52.6 \pm 16.9\%$ of the disk from available disk areas. However, in marked contrast, the SpineJet™ XL permitted removal of a mean $74.5 \pm 17.2\%$ of the disk. Furthermore, removal of the disk on contralateral portion was achieved more effectively using the SpineJet™ XL ($67.55 \pm 16.10\%$), as compared with the 31% previously reported by Javernick et al.⁹ using the TLIF approach.

The amount of the endplate cartilage removed using the SpineJet™ XL was insignificantly smaller than that removed using conventional instruments ($18.5 \pm 12.03\%$ vs. $22.8 \pm 17.84\%$: $p = 0.37$). On the other hand, the amount of endplate damage was significantly lower for the SpineJet™ XL ($3.2 \pm 5.18\%$ vs. $8.0 \pm 10.12\%$: $p < 0.05$). We attribute the removal of smaller amounts of endplate cartilage when using the SpineJet™ XL to a lack of skill or experience at endplate preparation and incomplete removal of cartilage from the endplates. Nevertheless, we did find

that the endplates were damaged more by conventional instruments than by the SpineJet™ XL.

Additionally, the number of insertions/withdrawals were significantly less for the SpineJet™ XL (20.4 ± 15.4 vs. 69.7 ± 36.7 : $p = 0.002$), which indicates that the use of the SpineJet™ XL during unilateral TLIF reduces the risk of damaging neural structures.

Regarding the time required to complete disk space preparation, the SpineJet™ XL enabled us to perform the task faster than when using conventional instruments. Furthermore, we found no significant differences between the two surgeons in terms of the extent of soft tissue removal, endplate cartilage removal, rates of endplate damage, and numbers of insertions and withdrawals, though there was intersurgeon difference in the duration of the entire disk preparation using conventional instruments.

CONCLUSION

In conclusion, the present study demonstrates that hydro-surgery using the SpineJet™ XL has the following advantages : it allows the preparation of a larger portion of the disk space, it is less traumatic, and it enables more precise endplate preparation without damaging the bony endplate. In addition, the SpineJet™ XL is a slender unit that provides various angles with long working channels and, thus, is less intrusive than conventional tools. Furthermore, the SpineJet™ XL appears to provide tangible benefits in terms of disk space preparation for graft placement, particularly when a unilateral TLIF approach is used. Future research should be aimed at determining the effect of improved disk preparation on fusion and on clinical results.

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