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Comparisons of Lumbar Muscle Performance Between Minimally-Invasive and Open Lumbar Fusion Surgery at 1-Year Follow-Up

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Abstract

Study Design: Prospective study.

Objective: Minimally-invasive lumbar fusion surgery (MIS) is a viable alternative to conventional open surgery (COS) for spinal disorders. Although MIS seems to be associated with less para-spinal muscle trauma, the actual back muscle performance after MIS and COS remain controversial. This study investigated post-operative para-spinal muscle performance, and the correlation between muscle dysfunction and clinical outcome.

Methods: In this prospective, non-randomized control study, 50 patients were enrolled and split into 2 groups: COS and MIS. We established a biomechanical model of the para-spinal muscle in the lumbar spine using electromyography (EMG) and specific muscle function tests. Functional outcomes were also reviewed and analyzed. All patients underwent EMG pre-operatively, and at 3 months and 1 year post-operatively. The para-spinal muscle performance was investigated by comparing the back muscle co-contraction ratio and the load transmission zone to the pre-operative data.

Results: Twenty-one patients in the COS group and 25 in the MIS group completed the study. Both groups showed a significant improved functional score. The abdominal and back muscle strengths were decreased post-operatively, and were then increased at 12 months post-operatively in both groups. During the perturbed balance task and static task, the MIS group exhibited a trend of recovery in comparison with the COS group. But, the back muscle performance at 12 months was poorer than the pre-op performance in both groups.

Conclusions: There was no significant difference in clinical outcome and para-spinal muscle performance between groups. In both methods, the global muscle function had declined post-operatively.

Keywords
minimally-invasive lumbar fusion surgery, electromyography (EMG), para-spinal muscle performance

Introduction

Minimally-invasive spine surgery has become more popular for spinal disorders; this lumbar fusion surgery is also thought to decrease the iatrogenic soft tissue trauma, and has been well-developed in the last decade.[1] Minimally-invasive lumbar fusion surgery (MIS) is a viable alternative to conventional open surgery (COS), with reduced blood loss and a shorter hospital stay.[2,3] According to previous studies, COS may result in extensive muscle trauma during the operation as compared with MIS.[4,5] Although direct muscle injury appears to be associated with post-operative muscle atrophy and a poor surgical outcome, in recent articles, similar clinical and radiographic outcomes between MIS and COS have been reported.[6-8]

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The actual back muscle performance and posture control after MIS and COS remains controversial. Most studies found para-spinal muscle post-operative changes on computed tomography (CT) or magnetic resonance imaging (MRI),[9,10] but the artifacts from metallic implants after spinal fusion surgery may interfere with the results. Therefore, the real post-operative para-spinal muscle performance should be investigated. According to previous studies, employing surface electromyography (EMG) and measuring the center of pressure (CoP) under specific muscle function tests are effective for evaluating the changes of the muscle function and posture control in patients with degenerative lumbar disease.[11,12]

The purpose of this study was to investigate the differences of the MIS and COS methods in terms of the lumbar muscle responses and postural control under the quiet standing (QS) task, weight-lifting (WL) task, and sit-to-stand (STS) tasks. Via *in vivo* comparative study, which surgical method resulted in less post-operative para-spinal muscle dysfunction and poor postural control was investigated.

Materials and Methods

Study Design

This prospective, non-randomized control study was approved by the Institutional Review Board (IRB) of our institute. Written informed consent was obtained from all study participants. Patients who suffered from low back pain with radiculopathy were enrolled in this prospective, non-randomized, non-blinded study. The inclusion criteria were the presence of single- or 2-level degenerative spondylolisthesis or spondylolytic spondylolisthesis in the lumbar and lumbosacral area. The exclusion criteria were as follows: patients who had received previous spine surgery; spine trauma; infection; psychological distress syndrome; malignant tumors; BMI >40 kg/m^2; aged younger than 18 years; pregnancy; allergies against Ni or Ti; and chronic neurological or musculoskeletal diseases that might cause impaired balance. Patients were enrolled from single medical center by doctor A and B. The COS was performed by doctor A and the MIS was performed by doctor B. In the COS group, the operation was performed using the free-hand surgical technique via the mid-line approach, while in the MIS group, the operation was conducted under the fluoroscope-assisted percutaneous instrumentation technique via the para-midline approach. Laminectomy was performed at the fusion level, with preservation of the adjacent supra and inter-spinous ligaments in the COS group (for example, decompressed lower L4 to upper L5 in L45 fusion surgery).[13] Using the expandable retractor for unilateral laminotomy and medial facetectomy were performed for disease-level decompression in the MIS group. All patients underwent transforaminal lumbar interbody fusion with a cage and transpedicle screws, and the COS group received unilateral or bilateral posterolateral spinal fusion depending on the volume of autogenous bone graft and the MIS group only received interbody fusion. All participants wore a Taylor brace for 3 months post-operatively.

Para-spinal muscle activities under function test, medical records, and functional outcomes (as assessed using a visual analog scale (VAS, 0–10), questionnaire and the Oswestry Disability Index (ODI) questionnaire and the Japanese Orthopaedic Association score (JOA) were reviewed and analyzed. All patients underwent the examination pre-operatively, and at 3 months and 12 months post-operatively.

Assuming some consistency, a minimum sample of 44 participants was required (MIS: 24 and COS: 20) with α=0.05 (significance level) and β=0.8 (statistical power).

Instrumentation. The trunk isometric strength was measured using a handheld dynamometer (MicroFET2, HOGGAN Health Industries, Inc., UT, USA) by employing the manual muscle testing technique. A surface wireless EMG system (Trigno Wireless System, Delsys Inc., Boston, MA, USA) was used to record muscle activation levels while performing the experimental tasks. The center of the electrode sensor for the rectus abdominis (RA) was placed 3 cm lateral and 2 cm superior to the umbilicus, and that for the erector spinae (ES) was placed at the L3 level and 3 cm lateral from the spinous processes.[14] The sampling rate of EMG was 1 kHz, and the acquired data was digitally band-pass filtered between 20 Hz and 450 Hz, full-wave rectified, and smoothed using a low-pass filter (time constant of 100 ms; Butterworth 8 order). The postural stability of participants during the experimental tasks was measured using a stationary force plate (Kistler 9260AA6, KistlerInstrumente AG, Winterthur, Switzerland). The EMG system and force plate were synchronized using a 32-channel 16-bit A/D board (NI USB-6218, National Instruments Co., USA).

Experimental procedure. At the beginning of the experiment, the isometric maximal voluntary contractions (MVC) of the trunk flexor and extensor were examined.[15] After sufficient rest, the performance of the participants in the 2 types of functional task, static and perturbed balance tasks, was examined. The first functional task was the QS task, in which participants were asked to stand still on the force plate with both hands placed comfortably on the thighs for 40 s.[16] Four standing conditions were tested: eyesopen and standing with a shoulder-width base (EOW), eyesclosed and standing with a shoulder-width base (ECW), eyesopen and standing with a narrow base, feet close together (EON), and eyesclosed and narrow-base standing (ECN). Second, the STS task required the participants to perform 5 consecutive stand-up and sit-down exercises on a regular stool as quickly as possible. The height of the stool could be adjusted to ensure a sitting posture with a 90-degree flexion of both hip and knee joints of the participants. They were asked to fold their arms across their chests throughout the test, and to stand-up with a complete erect posture and make firm contact when sitting. Then, the WL task required participants to lift weight of 6 kg from table to chest height. Participants were allowed a practice at a normal pace to ensure their understanding of the instructions prior to the actual test. Between each trial, the participants were allowed to rest in order to minimize fatigue. Three repetitions were recorded, and average values of the 3 repetitions were used in the ***Statistical analysis.***

Table 1. Demographic Data.

Parameter	COS	MIS	p-value
Sex (F/M)	14/7	13/12	0.268
Age	59.2 ± 8.6	60.2 ± 10.0	0.757
BMI	26.9 ± 3.6	25.4 ± 2.4	0.152
Surgical segment			
L2-3	0	1	
L3-4	0	2	
L4-5	15	16	
L5-S1	1	4	
L3-5	3	1	
L4-S1	2	1	
Operation data			
Surgical time (min)	180 ± 38	217 ± 38	0.01*
Blood loss (ml)	397.7 ± 243	246.8 ± 133.9	0.18
VAS (back)			
Pre-op	3.8 ± 2.7	3.2 ± 2.7	1.000
Post-op 3M	1.0 ± 1.6	0.7 ± 1.6	0.72
Post-op 1Y	1.0 ± 1.4	0.9 ± 1.7	0.99
VAS (leg)			
Pre-op	5.0 ± 3.3	3.8 ± 3.4	0.305
Post-op 3M	0.5 ± 1.2	0.4 ± 1.0	0.95
Post-op 1Y	0.5 ± 1.4	0.5 ± 1.5	0.72
ODI (%)			
Pre-op	31.8 ± 16.2	22.4 ± 14.6	0.168
Post-op 3M	9.8 ± 10.8	8.4 ± 10.4	0.96
Post-op 1Y	5.8 ± 6.2	4.2 ± 6.0	0.55
JOA	53.1 ± 6.2		
Pre-op	64.1 ± 7.0	56.3 ± 9.6	0.20
Post-op 3 M	64.5 ± 6.8	64.7 ± 6.6	0.77
Post-op 1Y		65.5 ± 6.9	0.66

*$p < 0.05$.

Data Analysis

During both the STS and QS tasks, the center of pressure (CoP) of the participants was analyzed, including the maximal anteroposterior (AP) and mediolateral (ML) displacements and sway area of the CoP.[12] For EMG, 1 s of the 5-second EMG signal during MVC of the extensor was used for normalization of the EMG amplitude. The ES activation levels were then calculated as the normalize daveraged integration of the EMG (NAIEMG). The ES muscle CCR was calculated according to the following equation[17]:

$$CCR = \sum NAIEMG_{Anta} \Big/ \sum NAIEMG_{Ago}$$

The subscript "Anta" indicated the antagonists (i.e. the extensors) and "Ago" (i.e. the flexors) indicated the agonist muscles.

The Kolmogorov-Smirnov test results indicated that all measurements in this study did not comply with the normal distribution, with the exception of the CCR. The independent t-test and Mann-Whitney U test were applied to compare the CCR and CoP movement (sway area) between the COS and MIS groups for each task. Repeated-measure analysis of variance (ANOVA) and the Friedman test were used to compare the differences in measurements between pre-op, 3 months post-operatively and 12 months post-operatively. Post hoc contrasts using Bonferroni correction and the Wilcoxon signed-rank test were also applied when significant effects were found. All data was analyzed using the statistical software SPSS (SPSS, Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$.

Results

Between Feb 2016 and Feb 2017, 50 participants were enrolled in this study. Four patients were not able to complete the study (2 patients suffered from other medical diseases and 2 were lost to follow-up) and were excluded. Finally, there were 21 patients in the COS group and 25 in the MIS group who completed the 1-year follow-up assessment. The patient demographic data, the segmental distributions, surgical data and functional scores for each group are presented in Table 1. There were no significant differences in terms of sex, age, VAS, ODI or JOA scores between groups, and all functional scores improved as compared with the pre-operative data. No post-operative neurologic complications, infection, or other adverse effects were noted in this study.

Maximal Voluntary Contractions (MVCs)

Regarding maximal voluntary contractions (MVCs), in the COS group, the trunk extension force pre-op, at 3 months and 1 year in the COS group was 6.8 ± 3.3, 6.1 ± 3.6 and 6.0 ± 1.3 Kg, respectively, and the values for the MIS group were 6.3 ± 3.5, 5.0 ± 2.7 and 6.0 ± 1.5 Kg, respectively. The flexion force pre-op, at 3 months and 1 year was 5.4 ± 2.7, 4.4 ± 2.4 and 4.8 ± 1.6 Kg, respectively, while the values for the MIS group were 5.2 ± 3.2, 3.7 ± 2.0 and 5.1 ± 1.4 Kg, respectively (Figure 1). The flexor and extensor muscle strengths were generally decreased at the 3-month follow-up point, with a statistically-significant decrease in the MIS group, and then increased at the 12-month follow-up point in both groups, with a larger increase in the MIS group; the strengths in both groups were lower at 12 months than they were pre-operatively, though the differences were not significant.

Co-Contraction Ratio (CCR)

The perturbed balance test under STS and WL revealed that the muscle CCR was increased at 3 months post-operatively, and approached the pre-operative results at 1 year post-operatively. Under the STS task, the pre-op, post-op 3 months and post-op 1-year CCRs were 0.88 ± 0.74, 1.05 ± 0.45 and 1.17 ± 0.69 in the COS group, respectively, and 1.11 ± 0.69, 1.29 ± 0.75 and 1.02 ± 0.73 in the MIS group, respectively. There was a weak trend of CCR improvement in the MIS group, but this was not statistically significant ($p = 0.53$) (Figure 2).

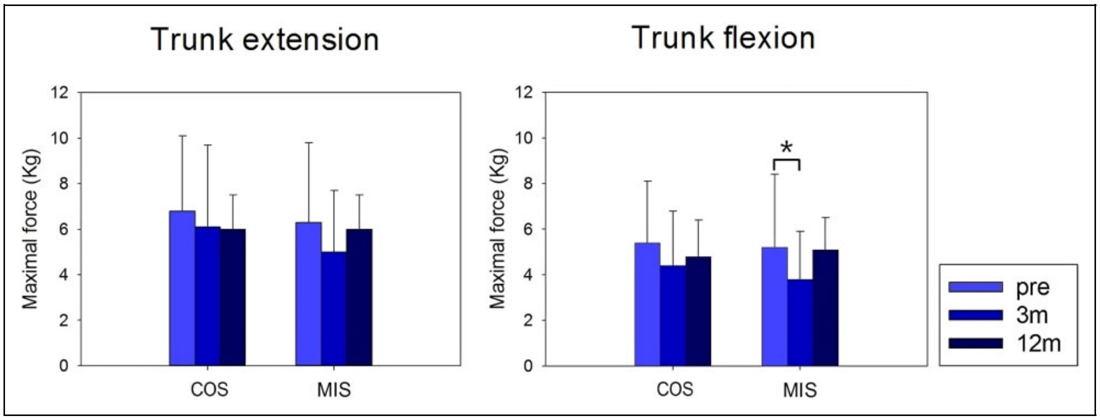

Figure 1. Isometric maximal voluntary contraction (MVCs) of the trunk flexor and extensor. (*$p < 0.05$).

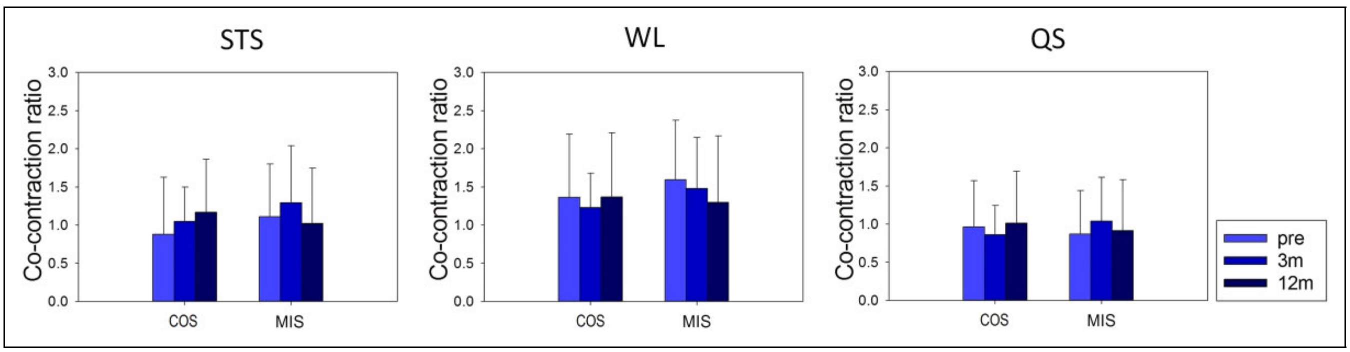

Figure 2. Co-contraction ration (CCR) under perturbed balance task (STS and WL) and static task (QS).

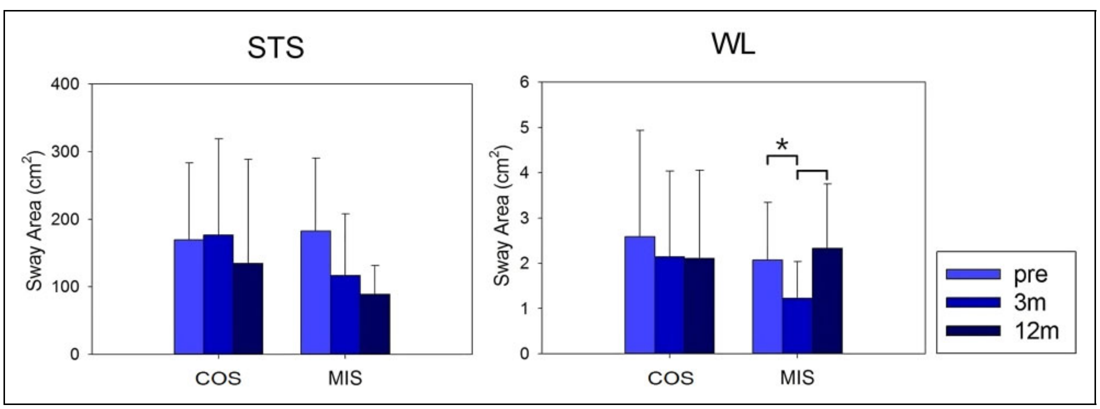

Figure 3. Center of pressure (CoP) sway area under perturbed balance task (STS and WL). (*$p < 0.05$).

The static test under QS for EOW, EON, ECW and ECN revealed that the CCR had increased at 3 months post-operatively, and approached the pre-operative status at 1 year post-operatively. The CCR had improved in the MIS group at the 1-year follow-up and had not in the COS group, but there was no significant difference (Figure 2).

Center of Pressure (CoP)

Under the STS test, the CoP sway area decreased persistently in the MIS group, but there was no significant difference between groups. Under the WL test, significant differences were observed between pre-op and post-op 3 months, and post-op 3 months and post-op 12 months, in the MIS group (Figure 3). The CoP sway area decreased in both groups under the perturbed balance task, and there was no significant difference between groups. After 1 year of follow-up, the CoP area in the MIS group exhibited a trend of recovery approaching the pre-operative status in comparison with the COS group, but there was no significant difference.

In the static tasks (QS: EOW, EON, ECW and ECN), the sway area decreased persistently in the COS group under the

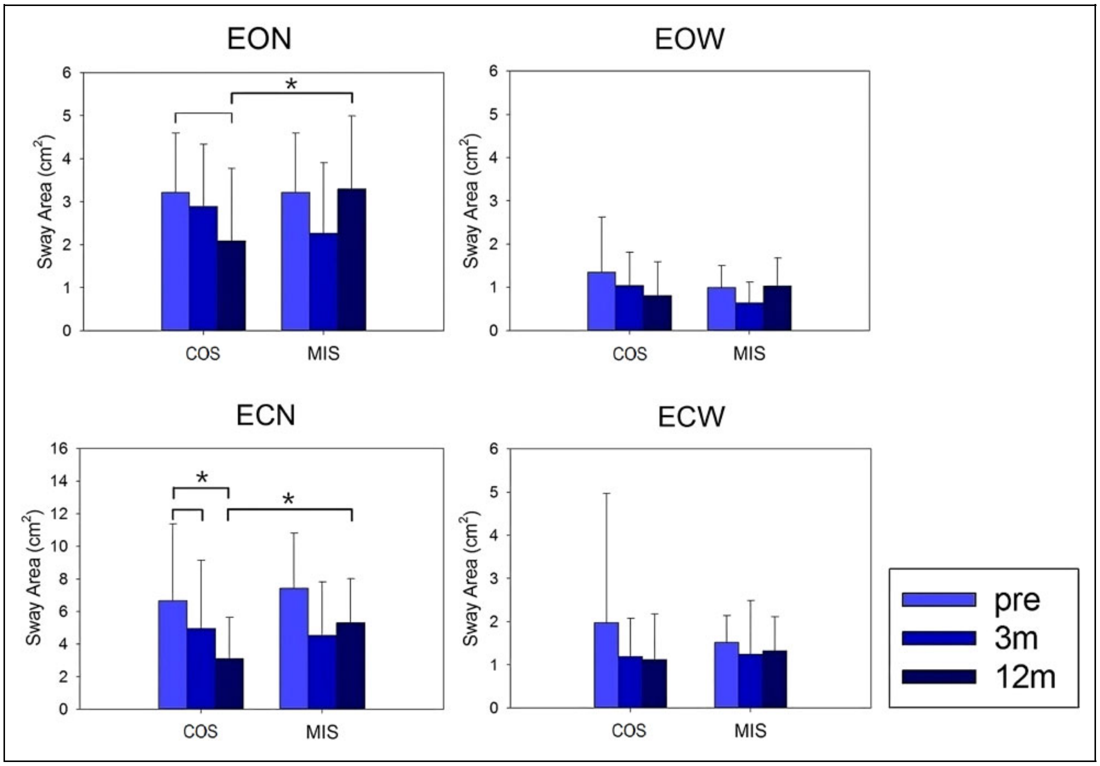

Figure 4. Central of pressure sway area under static task (EOW, EON, ECW and ECN) (*$p < 0.05$).

EON and ECN tasks, and significant differences were observed between pre-op and post-op, and post-op 12 months in the COS and MIS groups (Figure 4). The trend of a decrease in the CoP sway area was observed in both groups under the QS task post-operatively, but it had increased again at post-op 12 months in the MIS group.

Discussion

The advantages of minimally-invasive lumbar fusion surgery are less tissue damage, reduced back pain leading to a shorter rehabilitation period, and a quicker return to work and daily activities,[5-8] but whether or not it is related to fewer complications remains controversial.[2,3] Reviewing the literature, most authors found no significant differences in the short-term clinical outcome and radiographic outcome between COS and MIS groups.[6,7] In our study, we also found no significant differences between these 2 groups in functional scores. These results were similar to those of previous studies.

For evaluating soft tissue trauma post-operatively, most studies used imaging studies (CT or MRI) to evaluate the morphology of the para-spinal muscle, and revealed that MIS can decrease post-operative muscle atrophy as compared with COS.[18-20] However, Urrutia et al. suggested that single-level fat signal fractions and cross-sectional area are not representative of the whole lumbar spine.[21] Surface EMG is an objective and effective tool for evaluating back muscle function.[12,17,22] Waschke et al. performed EMG and found that para-spinal muscle atrophy and denervation were correlated with a poorer clinical outcome.[23] In a previous study, using the para-spinal muscle CCR under EMG and CoP movement evaluated the posture control between symptomatic degenerative lumbar disease patients and healthy individuals.[12] The symptomatic degenerative group had poor postural control and tended to rely on visual feedback and a wide-base standing posture, and a high level of erector spinae activation was required to maintain their postural steadiness.

In this study, we found that the MVCs (trunk flexion and extension force) decreased, the para-spinal muscle CCR increased, and the CoP sway area decreased post-operatively during the perturbed balance task (STS and WL) in both groups. The results revealed post-operative back muscle dysfunction, and the patients needed to activate other core muscles, resulting in an increased CCR. The CoP sway area decrease during active motion revealed poor posture control post-operatively. There was a trend toward back muscle dysfunction post-operatively in both groups, and mild improvement was observed in the MIS group at the 12-month follow-up. These results may indicate less soft tissue injury during MIS, but there were no significant differences between pre- and post-operatively or different surgical methods.

The smaller CoP sway area during the static task means better posture control as opposed to the perturbed balance task.[12,16] During the QS task, there were significant differences in the EON and ECN (narrowed stance) tasks between pre-op and post-op, and COS and MIS. The COS group revealed better posture control as compared with the MIS group, and the improvement persisted at the 12-month follow-up point, but the sway area had deteriorated at 12 months post-operatively in the MIS group. We assumed that the quiet standing control required greater lower-limb function than back function. Compared with MIS patients, the COS group may have received more radical neurologic decompression, resulting in better lower-limb function.

According to our results, there appeared to be no differences in post-operative muscle function and clinical outcome between the MIS and COS groups, and the muscle function had worsened at the 3-month follow-up point in some tasks. These results conflicted with the main aims of MIS, and should be investigated further. We assumed that MIS via splitting of the para-spinal muscle (erector spinae) will still result in erector spinae denervation and dysfunction. Putzier et al. identified injury to the longissimus muscle in a MIS-TLIF group as compared with a conventional PLIF group.[24] Hu et al. reported that the muscle-splitting approach may be an important cause of multifidus muscle denervation and atrophy.[9] The greater increase in CCR in the MIS group at 3 months post-operatively may reply on the results of previous study. Otherwise, all patients received spinal fusion surgery and wore a brace for 3 months after surgery. Immobilization of the spine may be another major factor resulting in para-spinal muscle dysfunction and poor posture control.

In conclusion, there was no significant difference in clinical outcome between groups. Although the MIS patients exhibited a trend of better recovery in global back muscle performance in terms of the back muscle strength and the objective para-spinal muscle function as compared with the COS patients post-operatively, the global muscle function still declined post-operatively. Our finding may explain why MIS did not result in a better clinical outcome.

Author Contribution

Meng-Ling Lu and Chih-Hsiu Cheng authors contributed equally to this work and share the first authorship. Ethics approval and consent to participate This study was approved by Chang Gung Medical Foundation Institutional Review Board (IRB No. 104-4548B). Verbal informed consent was obtained from all participants in this study.

Declaration of Conflicting Interests

The author(s) declared no conflicts of interest with respect to the research, authorship or publication of the article.

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