Effects of smoking on pedicle screw–based dynamic stabilization: radiological and clinical evaluations of screw loosening in 306 patients

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OBJECTIVE Cigarette smoking has been known to increase the risk of pseudarthrosis in spinal fusion. However, there is a paucity of data on the effects of smoking in dynamic stabilization following lumbar spine surgery. This study aimed to investigate the clinical outcomes and the incidence of screw loosening among patients who smoked.

METHODS Consecutive patients who had lumbar spondylosis, recurrent disc herniations, or low-grade spondylolisthesis that was treated with 1- or 2-level surgical decompression and pedicle screw–based Dynesys dynamic stabilization (DDS) were retrospectively reviewed. Patients who did not complete the minimum 2 years of radiological and clinical evaluations were excluded. All screw loosening was determined by both radiographs and CT scans. Patient-reported outcomes, including visual analog scale (VAS) scores of back and leg pain, Japanese Orthopaedic Association (JOA) scores, and Oswestry Disability Index (ODI), were analyzed. Patients were grouped by smoking versus nonsmoking, and loosening versus intact screws, respectively. All radiological and clinical outcomes were compared between the groups.

RESULTS A total of 306 patients (140 women), with a mean age of 60.2 ± 12.5 years, were analyzed during an average follow-up of 44 months. There were 34 smokers (9 women) and 272 nonsmokers (131 women, 48.2% more than the 26.5% of smokers, $p = 0.017$). Postoperatively, all the clinical outcomes improved (e.g., VAS back and leg pain, JOA scores, and ODI, all $p < 0.001$). The overall rate of screw loosening was 23.2% (71 patients), and patients who had loosened screws were older (61.7 ± 9.6 years vs 59.8 ± 13.2 years, $p = 0.003$) and had higher rates of diabetes mellitus (33.8% vs 21.7%, $p = 0.038$) than those who had intact DDS screws. Although the patients who smoked had similar clinical improvement (even better VAS scores in their legs, $p = 0.038$) and a nonsignificantly lower rate of screw loosening (17.7% and 23.9%, $p = 0.416$), the chances of secondary surgery for adjacent segment disease (ASD) were higher than for the nonsmokers (11.8% vs 1.5%, $p < 0.001$).

CONCLUSIONS Smoking had no adverse effects on the improvements of clinical outcomes in the pedicle screw–based DDS surgery. For smokers, the rate of screw loosening trended lower (without significance), but the chances of secondary surgery for ASD were higher than for the nonsmoking patients. However, the optimal surgical strategy to stabilize the lumbar spine of smoking patients requires future investigation.

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KEYWORDS Dynesys dynamic stabilization; smoking; screw loosening; adjacent segment disease; spondylolisthesis

SMOKING has deleterious effects on spinal fusion surgery. In the literature of spine surgery, smoking could be associated with lower fusion rates,^{1–4} higher complication rates,^{5–7} and longer hospitalization.⁸ Biological and clinical data have also demonstrated that

smoking adversely affects bone growth and arthrodesis in commonly performed cervical or lumbar spinal fusion surgery.^{9–11} With emerging technology aiming at preservation of spinal segmental mobility after surgery, which includes cervical disc arthroplasty (CDA) and lumbar dy-

ABBREVIATIONS ASD = adjacent segment disease; CDA = cervical disc arthroplasty; DDS = Dynesys dynamic stabilization; DM = diabetes mellitus; HU = Hounsfield units; JOA = Japanese Orthopaedic Association; ODI = Oswestry Disability Index; VAS = visual analog scale.

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dynamic stabilization, it has become reasonable to doubt that smoking affects spinal surgery that is not aimed at fusion. Moreover, a recent report on CDA indicated that segmental mobility was slightly better preserved in smokers, and thus CDA might be a better option than anterior cervical fusion for patients who smoke.¹² However, there has been no study on the effects of smoking in dynamic stabilization surgery of the lumbar spine.

Pedicle screw–based dynamic stabilization has been reported as an effective and viable option in surgical management of lumbar spondylosis.^{13–18} As opposed to fusion, the most commonly raised question regarding these screws, which do not aim to fuse the spine, is their risk of loosening. This risk in pedicle screw–based dynamic stabilization has reportedly been approximately 5% per screw and 20% per patient in 2–5 years postoperatively.^{19–21} Theoretically, the demands of mechanical strength and durability for these dynamic screws are higher than for the conventional screws designed for fusion. However, the concept of dynamic stabilization, rather than fusion, might neutralize such needs because the goal is to maintain controlled motion in the lumbar spine. Thus, we were curious when it comes to patients who smoke. Could the smoking patients, who are traditionally regarded as nonideal candidates for fusion, be better managed by dynamic stabilization because pseudarthrosis is prone to happen anyway?

Because it remained elusive in the literature how smoking would affect surgery aimed at preserving spinal motion rather than fusion, the present study aimed to evaluate the incidences of screw loosening in patients who smoked and who underwent dynamic stabilization. The clinical outcomes and reoperation rates also were compared among the nonsmokers and the smokers. To date, this is the first study to address the effects of cigarette smoking on dynamic stabilization surgery of the lumbar spine.

Methods

Patient Population

Consecutive patients who underwent posterior laminectomy decompression and placement of a 1- or 2-level Dynesys dynamic stabilization (DDS) system (Zimmer Spine) between 2006 and 2015 were reviewed retrospectively. The clinical presentations of the patients in this series included mechanical low-back pain, focal radiculopathy, or neurogenic claudication. The common pathologies indicated for surgery were spinal stenosis with hypertrophy of the ligamentum flavum, facet degeneration, minimal or mild spondylolisthesis, degenerative disc disease, and recurrent disc herniation. Patients who had Meyerding grade 2 spondylolisthesis, severe facet degeneration, marked coronal or kyphotic deformity, or disc disease that caused arthrodesis prior to surgery were excluded. If the patients' segmental motion on dynamic lateral radiographs was less than 3° preoperatively, they were designated for fusion surgery rather than DDS. Those patients who were lost to follow-up within 2 years or did not complete evaluations at each time point were also excluded from the analysis.

All patients were separated into 2 groups according to their history of cigarette consumption before surgery. The

patients were grouped into smokers if they had consumed cigarettes within 6 months before surgery, or nonsmokers if they had not smoked at all or within 6 months of DDS surgery.

Surgical Technique

The patient was placed prone under general anesthesia with neutral lumbar lordosis and an adequate cushion. A midline skin and fascia incision was made, followed by adequate decompression with total laminectomy and bilateral foraminotomies. The hypertrophied ligamenta flava in the narrowed lateral recesses were decompressed with Kerrison rongeurs and probed through to free the nerve roots from compression. Caution was used during decompression of the lateral recesses, so that the facet joints were mostly preserved, with resection of no more than the medial one-third of each facet joint at the indexed level in selected cases, when necessary. After decompression, bilateral fascial incisions were made to approach directly through the Wiltse plane to the junction of the lateral facet joint and the transverse process. The Dynesys pedicle screws were placed, and the positions were confirmed by intraoperative fluoroscopy in every case. Throughout the process, the facet joints were minimally exposed to prevent the violation of joint capsules and to ensure the integrity of the facet joints. The diameter and length of the Dynesys screws (closed-head, nonhydroxyapatite-coated, titanium alloy) were estimated by both preoperative CT and a pedicle sounder instrument intraoperatively. Special attempts were made to avoid removing and reinserting the screws due to the self-tapping design of the Dynesys screws. After placement of all screws, the polycarbonate urethane spacers were cut into appropriate lengths, measured by the pedicle distraction gauge to ensure neutral lordosis in the indexed level during extension. The elastic spacers were assembled with polyethylene-terephthalate cords to provide controlled forward flexion movement. Theoretically, all patients were stabilized in a neutral to slightly lordotic position after DDS.

Clinical Evaluations

Our database was built prospectively and reviewed retrospectively. Scheduled clinical and radiological examinations for selected patients, including standard pre- and postoperative questionnaires and clinical evaluations, were aimed to be completed at 1.5, 3, 6, 12, and 24 months after surgery, and with a 12-month interval thereafter between each clinical visit. The functional evaluations included the Japanese Orthopaedic Association (JOA) scores and the Oswestry Disability Index (ODI) scores. The pain scores included visual analog scale (VAS) for back and leg pain. All the subjective questions were answered by the patients themselves. The objective assessment was performed by the 2 special nursing assistants under the supervision of the physicians and with the informed consent of patients.

Radiographic Evaluations

Preoperative standard anteroposterior and dynamic lateral radiographs, MRI, and CT scans were arranged in all patients for evaluation. Postoperative follow-up at 1.5, 3, 6,

FIG. 1. Radiographic studies obtained in a 45-year-old man (nonsmoker) who had a recurrent ruptured disc at L5/S1 2 years after microdiscectomy. He received L5 laminectomy and L5/S1 DDS surgery. Preoperation (A) and postoperation (B) lateral views of the lumbar spine for the second surgery revealed a preserved height of the L5/S1 disc after a follow-up of 2 years. Anterior-posterior view (C) shows no screw loosening.

12, and 24 months after surgery and yearly thereafter included both plain and dynamic radiographs. Follow-up CT scans and MRI were undertaken at approximately 18 and 24 months after surgery. Similar to previous publications on Dynesys screw loosening,^{19–21} screw loosening was defined as an initial halo sign (radiolucent line around the implant > 1 mm wide) followed by a double-halo sign on

lateral radiographs or CT scans (Figs. 1 and 2). The measurement was performed using quantitative measurement analysis software (SmartIris, Taiwan Electronic Data Processing Co.). Radiographic interpretations were made by 2 independent radiologists and 2 neurosurgeons, and the coauthors made the final decision if there was any ambiguity among interpretations.

FIG. 2. Neuroimaging studies obtained in a 61-year-old man (nonsmoker) who underwent screw removal because of root compression by a broken screw 6.5 years after initial L3–4–5 DDS surgery. **A and B:** Anterior-posterior and lateral radiographic views of the lumbar spine. **C and D:** Axial CT views of L3 and L5. Arrowheads: double-halo loosening sign. Arrows: broken right L5 screw.

TABLE 1. Demographic data in 306 patients who underwent DDS

Characteristic	Value
No. of patients	306
No. of screws	1590
Age (yrs)	60.2 ± 12.5
Sex (F/M)	140:166
Mean follow-up (mos)	44.0 ± 18.0
DM (%)	75 (24.5)
HTN (%)	145 (47.4)
Smoking (%)	34 (11.1)
Indexed level; bridged disc (%)	
1 level	123 (40.2)
2 levels	183 (59.8)
S1 involvement (%)	71 (23.2)
Screw loosening (%)	
By person	71 (23.2)
By screw	153 (9.6)
Screw breakage (%)	
By person	7 (2.3)
By screw	9 (0.6)
Periop complications (%)	9 (2.9)
Secondary op for ASD (%)	8 (2.6)

HTN = hypertension.

Values are presented as either the mean ± SD or the number of patients (%).

Statistical Analysis

The SPSS commercial software (SPSS, Inc.) was used to perform all statistical analyses. Independent t-tests and paired t-tests were applied for continuous variables, and the Fisher exact test was used for categorical data. The chi-square test was used for relation verification for 2 variables. A p value of 0.05 was considered statistically significant.

Results

Demographics and Clinical Outcomes

Among the 549 consecutive patients who underwent DDS in this series, 306 (55.7%) met the inclusion criteria and had completed all the postoperative clinical and radiological evaluations for more than 24 months. The mean follow-up duration was 44.0 ± 18.0 months. The patients' mean age was 60.2 ± 12.5 years at the time of surgery; 140 (45.8%) were female (Table 1).

Of the 306 patients analyzed, 123 (40.2%) underwent 1-level (bridged disc) and 183 patients (59.8%) underwent 2-level DDS after decompression. Seventy-one patients (23.2%) had screws implanted in the S1 level. The overall clinical outcomes, measured by VAS back and leg pain, JOA scores, and ODI were significantly improved at 3, 12, and 24 months after surgery compared with scores at pre-operation (all p < 0.001; Table 2).

There were 9 patients (2.9%; Table 1) who suffered from perioperative complications directly related to the surgery, including 1 hematoma with cauda equina syndrome (reoperation performed on postoperative day 3); 2

TABLE 2. Preoperative and postoperative clinical characteristics in 306 patients who underwent DDS

Scoring System	Preop	Postop	p Value
VAS (back)	5.4 ± 3.2	2.5 ± 2.7	<0.001
VAS (leg)	6.5 ± 3.0	2.3 ± 2.8	<0.001
JOA	4.5 ± 3.7	9.1 ± 4.0	<0.001
ODI	26.8 ± 8.9	11.3 ± 9.4	<0.001

Clinical outcome scores are presented as the mean ± SD. Boldface type indicates statistical significance.

inadvertently fixed drainage tubes by closing sutures (both surgically removed on postoperative day 3); 1 screw malposition (revision of the screw on postoperative day 15); 2 superficial wound infections; 2 deep infections with osteomyelitis; and 1 deep vein thrombosis. Two patients had abscess formation 2–3 years after the initial surgery and received debridement and subsequent removal of screws and the DDS system entirely. Eight patients (2.6%) in the series received a secondary surgery for adjacent segment disease (ASD) within 3–8 years after DDS. Screw breakage with root compression was found in 1 patient (a 61-year-old man who was a nonsmoker) and eventual removal of screws was done approximately 6.5 years postoperatively (Fig. 2).

Screw Loosening

Among the 306 patients followed for approximately 3.67 years (mean 44.0 ± 18.0 months), screw loosening was radiologically identified in 71 patients (23.2%), or 153 of 1590 screws (9.6%). The mean age of patients with loosened screws was older by almost 2 years than those patients without loosening (61.7 ± 9.6 years vs 59.8 ± 13.2 years, p = 0.003; Table 3). Sex, mean follow-up time, numbers of bridged levels, and S1 involvement were all similar in the 2 groups (all p > 0.05). In patients with diabetes mellitus (DM), the rate of screw loosening was significantly higher than that in patients without DM (33.8% vs 21.7%, p = 0.038). The percentages of smoking or S1 involvement were similar in the 2 groups (both p > 0.05; Table 3).

The screw loosening caused little adverse effect on clinical outcomes, because all the patients' reported outcome measurements (i.e., VAS back and leg pain, JOA scores, and ODI scores) were similar between the 2 (intact vs loosened screw) groups. The perioperative complications and secondary operations due to ASD were also similar (all p > 0.05), regardless of whether the patients had screw loosening or not. Among the 71 patients with screw loosening, 7 patients (9.9%) had screw breakage during follow-up, but only 1 patient was symptomatic and later underwent surgical removal because of refractory radicular pain.

Smoking

There were 34 cigarette smokers (11.1%) in this series. Among these smoking patients, the mean age, follow-up period, indexed levels of operation, and the percentage of S1 involvement were all very similar to those of the nonsmokers, except that there was a female predominance

TABLE 3. Comparison between groups of patients with intact or loosened screws after undergoing DDS

Variable	Intact Screw, n = 235	Loosened Screw, n = 71	p Value
Age (yrs)	59.8 ± 13.2	61.7 ± 9.6	0.003
Sex (F/M)	112:123	28:43	0.223
Mean follow-up (mos)	44.0 ± 17.7	44.1 ± 19.2	0.833
DM (%)	51 (21.7)	24 (33.8)	0.038
HTN (%)	105 (44.7)	40 (56.3)	0.085
Smoking (%)	28 (11.9)	6 (8.5)	0.416
Levels; 1:2	97:138	26:45	0.483
S1 involvement (%)	49 (20.9)	22 (31.0)	0.076
Clinical outcomes postop			
VAS (back)	2.4 ± 2.7	2.6 ± 2.4	0.628
VAS (leg)	2.3 ± 2.9	1.5 ± 2.2	0.128
JOA	9.4 ± 4.3	10.0 ± 3.2	0.404
ODI	11.1 ± 9.7	10.9 ± 8.0	0.932
Periop complications (%)	6 (2.6)	3 (4.2)	0.465
Secondary op for ASD (%)	5 (2.1)	3 (4.2)	0.332

Values are presented as either the mean ± SD or the number of patients (%). Boldface type indicates statistical significance.

(48.2% vs 26.5%, $p = 0.017$) among the nonsmokers (Table 4).

Surprisingly, smoking did not cause more screw loosening in the series. There was no significant difference in the incidences of screw loosening between the smoking and nonsmoking patients. In fact, the smokers even had a trend (without significance) toward fewer loosened screws (17.7% vs 23.9% by person [$p = 0.416$], or 6.8% vs 10.0% by screw). Although the 7 patients who had broken screws were all nonsmokers, there was no statistical difference ($p = 0.344$).

Last but not least, the overall clinical outcomes (e.g., VAS, JOA scores, and ODI) were similar in smokers and nonsmokers, except that VAS leg pain was significantly lower in smokers (0.8 ± 1.6 vs 2.3 ± 2.9 , $p = 0.038$) in the current series. Furthermore, there were no differences in the perioperative complication rates between the 2 groups (smoking vs nonsmoking, $p = 0.282$). However, the smokers had a higher rate of subsequent secondary surgery for ASD (11.8% vs 1.5%, $p < 0.001$; Fig. 3).

Discussion

To date, this study is the largest series of DDS (306 patients with a mean follow-up of 44 months) focusing on the radiological and clinical outcomes of smoking patients. The incidences of screw loosening were carefully evaluated by radiographs and confirmed by CT scans. For the degenerative disorders treated, among 306 patients (140 women, mean age 60.2 ± 12.5 years) with 1- or 2-level DDS, all the patients reported that clinical outcome measurements significantly improved after surgery. Overall, screw loosening was found in 71 patients (23.2%), and interestingly this seldom affected the clinical outcomes. There was only 1 patient who needed surgery for screw removal because of radicular pain probably related to the

broken screw. Moreover, smoking was associated with nonsignificantly lower screw loosening rates (17.7% vs 23.9%, $p = 0.416$) and a significantly lower VAS leg pain score (0.8 ± 1.6 vs 2.3 ± 2.9 , $p = 0.038$), but a higher rate of secondary surgery for ASD (11.8% vs 1.5%, $p < 0.001$) than for the nonsmoking patients in the study. The results were compatible with other published series that showed that screw loosening was usually asymptomatic and did not adversely affect improvement in the clinical outcomes. For the first time, this study demonstrated that cigarette smoking also did not affect the clinical outcomes of DDS for surgical management of lumbar spondylotic disorders.

It has been acknowledged that cigarette smoking affects spinal fusion and the surgical outcomes in many ways. Smoking causes osteoporotic change by increasing vertebral and endplate porosity and decreasing trabecular thickness, and could result in estrogen imbalance by increasing the cortisol level.⁹ A number of studies have demonstrated that, after lumbar spinal fusion surgery, smoking was associated with higher rates of pseudarthrosis or nonunion.^{1,3,4}

Despite many studies having reported on the effects of smoking in lumbar spinal fusion surgery, there were no reports addressing the issue of smoking in relation to DDS surgery, the nonfusion option for instrumentation of the lumbar spine. Pseudarthrosis and nonunion are problematic in fusion surgery, and so is screw loosening in DDS. Because there is no rigid fusion construct in DDS, the long-term repetitive demands on the mechanical strength and durability of the screws are expected to be extremely high over time. In a literature review, 11.7% (0%–73.5%) of patients had pedicle screw loosening and 1.6% (0%–8.1%) of patients had pedicle screw breakage.²² The remarkably wide variation in the reported rates of screw loosening could be attributed to the method used for detection and the definition of loosening. The known risk factors

TABLE 4. Comparison between groups of nonsmoking and smoking patients who underwent DDS

Variable	Nonsmoker*	Smoker*	p Value
Age (yrs)	60.6 ± 12.5	56.9 ± 12.4	0.101
Sex (F/M)	131:141	9:25	0.017
Mean follow-up (mos)	44.1 ± 18.1	43.8 ± 17.9	0.934
DM (%)	68 (25.0)	7 (20.6)	0.573
HTN (%)	133 (48.9)	12 (35.3)	0.134
Screw loosening (%)			
By person	65 (23.9)	6 (17.7)	0.416
By screw	141 (10.0)	12 (6.8)	0.486
Screw breakage (%)			
By person	7 (2.6)	0 (0)	0.344
By screw	8 (0.6)	1 (0.6)	0.910
Segments; 2:3	109:163	14:20	0.902
S1 involvement (%)	63 (23.2)	8 (23.5)	0.962
Clinical outcomes postop			
VAS (back)	2.6 ± 2.7	1.4 ± 1.6	0.092
VAS (leg)	2.3 ± 2.9	0.8 ± 1.6	0.038
JOA	9.3 ± 4.2	10.8 ± 2.7	0.173
ODI	11.4 ± 9.6	8.2 ± 5.6	0.178
Periop complications (%)	7 (2.6)	2 (5.9)	0.282
Secondary op for ASD (%)	4 (1.5)	4 (11.8)	<0.001

Values are presented as either the mean ± SD or the number of patients (%). Boldface type indicates statistical significance.

* In the nonsmoker subgroup there were 272 patients and 1414 screws; in the smoker subgroup there were 34 patients and 176 screws (total 306 patients with 1590 screws).

in screw loosening are old age and serum glucose level (i.e., DM).^{19,21} In the present study, 23.2% of patients had screw loosening and 2.3% of patients had pedicle screw breakage. Although the screw loosening rate was higher than the average reported data in the review study, it was much closer to our previous reports (19.7%–19.8%), and the screw breakage rate was even lower than that reported for lumbar spinal fusion surgery (4%–6%).²¹ Compared with nonsmokers, smokers had a nonsignificantly lower rate of screw loosening (17.7% vs 23.9%, $p = 0.416$).

The presence of osteoporosis could result in screw

FIG. 3. Bar graph showing comparisons of smokers and nonsmokers for screw loosening, screw breakage, perioperative complications, and secondary surgery due to ASD. Asterisks: significant differences.

loosening. However, due to the regulations of the National Health Insurance of Taiwan, in this series dual x-ray absorptiometry was reserved only for high-risk patients. Thus, only a portion of patients analyzed, including those who were older than 65 years of age or who had risk factors such as long-term steroid consumption, had actual data for bone density. There have been reports that have demonstrated that Hounsfield units (HU) measured on CT scans correlated well with the dual x-ray absorptiometry scores and could be used as a proxy to access the bone density.^{23,24} In the current series, the mean HU of the lumbar spine in the 34 patients who smoked was 144.7 ± 60.9 , which could be considered normal in Schreiber's series (mean 133.0 ± 37.6 HU)²⁴ and within the cutoff value of osteopenia in Wagner's series (≤ 150.1 HU).²⁵ Although osteoporosis could increase the chances of screw loosening, in this study it was an insignificant issue that would not affect the results.

It was also elusive what other side effects smoking could cause in DDS lumbar surgery. Regarding perioperative complications, studies in the literature demonstrated higher rates (especially infectious complications) or delayed wound healing in smoking patients.^{11,26} However, there was one study that suggested that smoking might not affect early (30-day) perioperative morbidity or mortality.⁸ Postoperative surgical site infection is a bothersome complication that frequently causes delayed recovery, longer hospital stay, and can progress into further morbidities. In this study, the perioperative complication rate of DDS

was 2.9%, which was compatible with the reported complication rates in other series of lumbar fusion surgery,²² and there was no significant difference between smokers and nonsmokers (5.9% vs 2.6%, $p = 0.282$). Therefore, although smoking could cause not only pseudarthrosis but also wound infections in patients with lumbar fusion, this seemed not to be the case for DDS lumbar surgery. However, the question of whether smoking patients should undergo DDS rather than fusion is beyond the scope of the current study. A prospective study that can randomize smoking patients for either DDS or fusion would better answer that question.

In previous studies with long-term follow-up after lumbar spine surgery, the clinical outcomes were either inferior in smokers compared with nonsmokers, after decompressive surgery with or without spinal fusion,²⁷ or similar after decompression surgery in the 2 groups.²⁸ The outcomes after DDS in smokers have not been discussed before. In our study, smokers had a significantly lower VAS leg pain score (0.8 ± 1.6 vs 2.3 ± 2.9 , $p = 0.038$) than nonsmokers. This unexpected result suggested that after DDS surgery, even smokers could have satisfactory clinical outcomes. Nevertheless, the analgesic effect of nicotine in patients who had sciatica was uncertain. In the literature, there was modest evidence that cigarette smoking might be associated with less pain in patients with spinal disorders.^{29–31} The effect of nicotine in pain relief, if any, would probably be multifactorial, including psychological and pharmacological factors, and could even include effects of other compounds in different brands of tobacco on the market. The postoperative improvement in pain scores demonstrated in patients who smoked was an issue of more complexity, because it would need to consider the amount of nicotine consumption after the surgery and the differences pre- and postoperation, which was beyond the scope of the current study. However, the issue of cigarette smoking in patients who undergo lumbar spinal surgery, whether fusion or DDS, warrants further investigation.

The actual goal for preservation of segmental mobility and reduction of ASD in DDS remained equivocal.^{14,15,17,18,32} Despite the fact that DDS is designed to stabilize the spine while allowing controlled motion, limited motion at the instrumented level of the lumbar spine has been reported, which can cause an overload of the adjacent segments and result in ASD. In the review study, 3.7% (0%–8.4%) of patients underwent secondary reoperation due to ASD, which was lower than fusion surgery (13%).²² The reoperation rate due to ASD in our study was 2.6%, which was significantly higher in smokers (11.8% vs 1.5%, $p < 0.001$). Various factors could account for the development of ASD, including the surgical approach, natural history, or individual patient characteristics. The known risk factors included preexisting disc degeneration at the adjacent level, long-segment fusion, older age, osteoporosis, intraoperative proximal facet violation, and higher body mass index.¹⁷ Also, tobacco exposure promoted disc degeneration and lumbar disc herniation,^{33,34} which might hasten disc degeneration at adjacent levels. Previous reports demonstrated that the claimed protective effects against ASD by DDS remained uncertain and warrant future investigation.^{17,18} Because the primary endpoints of the study were

the clinical outcomes, including neurological function, screw loosening, and reoperations, future investigations are warranted for the effects of smoking on ASD. Ideally, although this is not practical in our institution, further studies could randomize patients who are smokers for fusion or dynamic stabilization to investigate the incidences of ASD and long-term outcomes of DDS in smokers.

There are limitations to this study. There were less than an ideal number of smoking patients who could be included for analysis. Due to the retrospective nonrandomized nature of this cohort, the present study could only yield a 1:8 comparison of smokers to nonsmokers. Furthermore, the study did not address the relationship of nicotine dosage to all the outcomes measured. The study only addressed perioperative cigarette consumption according to the patients' subjective reports. There were no data on perioperative serum nicotine level, cigarette cessation, or even the amount consumed immediately postoperation, which might all influence the screw loosening rates as well as the clinical outcomes. The study only addressed preoperative cigarette consumption and simplified the postoperative exposure, which might have played an even more crucial role in the outcomes and complications of DDS.

Furthermore, there was no fusion group—which remains the standard surgical treatment for many lumbar spondylotic problems—as a comparison group in the study. Patients who opted to undergo DDS might be inherently healthier and have less degeneration, no deformity, and better bone quality. Therefore, a larger number of patients, a longer follow-up term, and measurement of the amount of cigarette exposure prior to and after the DDS surgery would provide more information about the effects of smoking on these patients who needed lumbar spine surgery. It remained unclear for smoking patients whether DDS was superior to lumbar fusion.

However, despite those limitations, this was the first study to focus on the relationship between smoking and outcomes in DDS surgery. To date, it also has the largest number of patients reporting on the incidences of screw loosening and outcomes of DDS surgery, with a decent mean follow-up of nearly 4 years. Therefore, DDS might be a reasonable alternative to fusion surgery for patients with lumbar disc herniation or spondylosis with minimal spondylolisthesis.

Conclusions

Smoking had no adverse effects on the improvements of clinical outcomes in pedicle screw-based DDS surgery. For smokers, the rates of screw loosening trended lower (without significance), but the chances of secondary surgery for ASD were higher than in the nonsmoking patients. However, the optimal surgical strategy to stabilize the lumbar spine of patients who smoke requires future investigation.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Huang, JC Wu. Acquisition of data: YH Kuo, CH Kuo, HK Chang, Tu, Fay, CC Chang. Analysis and interpretation of data: YH Kuo. Drafting the article: YH Kuo. Critically revising the article: JC Wu. Reviewed submitted version of manuscript: JC Wu. Approved the final version of the manuscript on behalf of all authors: Huang. Statistical analysis: YH Kuo. Administrative/technical/material support: Huang, CH Kuo, HK Chang, Tu, Fay, CC Chang, Cheng, CL Wu, Lirng, JC Wu. Study supervision: Huang, Cheng, JC Wu.

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