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Original Article

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# Open Versus Minimally Invasive Spine Surgery in the Treatment of Single-Level Degenerative Lumbar Spondylolisthesis: An AO Spine Global Cross-Sectional Study

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**Objective:** This study aims to assess global trends in the use of open surgery versus minimally invasive surgery (MIS) for the treatment of single-level L4–5 degenerative lumbar spondylolisthesis (DLS).
**Methods:** A cross-sectional online survey issued by the AO Spine Knowledge Forum Degenerative was conducted among AO Spine members between July and September 2023. Participants were presented with 3 clinical cases of L4–5 grade 1 DLS, each with varying degrees of stenosis and instability. The survey captured surgeon demographics and preferences for open versus MIS approaches. Statistical analysis, including chi-square tests and logistic regression, was performed to explore associations between surgical choices and surgeon demographics.
**Results:** A total of 943 surgeons responded, with 479 completing the survey. Open surgery was the preferred approach in all 3 cases (58.8%, 57.3%, and 42.4%, respectively), particularly in cases involving central and bilateral foraminal stenosis. MIS was the second most common choice, particularly for unilateral foraminal stenosis with mild instability (38.8%). Surgeons' preferences varied significantly by region, age, and fellowship training, with younger and fellowship-trained surgeons more likely to prefer MIS.
**Conclusion:** The study highlights the continued predominance of open surgery for DLS, especially in complex cases, despite the growing acceptance of MIS. Significant regional and demographic variations in surgical preferences suggest the need for tailored guidelines and standardized training protocols to optimize patient outcomes. Future research should focus on the long-term efficacy of these approaches and the impact of evolving technologies on surgical decision-making.

**Keywords:** Spondylolisthesis, Open surgery, Minimally invasive spine surgery, Fusion, Indirect decompression, Survey

## INTRODUCTION

Degenerative lumbar spondylolisthesis (DLS) is defined as the anterior translation of one lumbar vertebra on an adjacent vertebra with an intact neural arch. It occurs most frequently at L4–5 in individuals above the age of 40, with a male-to-female ratio of up to 1:6.[1] While most DLS cases are asymptomatic or associated with mild low back pain (LBP), progressive vertebral slippage may cause spinal canal encroachment, resulting in central or foraminal stenosis.[2] In patients with radiculopathy and/or neurogenic claudication who did not improve with conservative treatments, or who develop new-onset neurologic deficits, surgical treatment of DLS may be indicated.[3,4]

The goal of surgery in patients with symptomatic DLS is to treat the presenting symptoms of LBP, leg pain, or both. This is accomplished by decompressing the neural elements with or without the addition of lumbar fusion. Fusion procedures can involve anterior and/or posterior instrumentation with or without interbody cages.[5] To date, several techniques have been successfully employed to treat DLS, including traditional open surgical decompression through laminectomy or laminotomy with or without facetectomy, anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF).[6] In the last 2 decades, anterolateral lumbar approaches such as lateral lumbar interbody fusion (LLIF) or oblique lateral interbody fusion (OLIF) as an exclusive or adjunct approach for DLS have been demonstrated to provide successful outcomes while reducing surgical invasiveness.[7] These techniques primarily operate on the principle of indirect decompression, where neural decompression is achieved by opening the foramina and expanding the epidural space through disc space distraction, without the need to resect the compressive tissue.[8]

The recent advent of minimally invasive surgery (MIS) in spine care and its applications (e.g., tubular decompression, endoscopic surgery, navigation, etc.) has further advanced the treatment of DLS by minimizing postoperative pain, shortening recovery, reducing blood loss, decreasing soft tissue damage, and preserving paraspinal structural integrity.[9] Regarding DLS, MIS has been associated with lower intraoperative blood loss, shorter hospitalization, and equal outcomes compared to open surgery.[10] Despite the increasing number of surgical treatment options available for DLS, current guidelines do not recommend one approach over another.[3]

The aim of this study was to assess the global trends regarding the use of open surgery vs. MIS approaches in the treatment of single-level L4–5 DLS among AO Spine members worldwide. We analyzed the data extracted from an online survey consisting of 3 DLS cases with different severity, disease extent, and symptom patterns to assess surgeons' preferences in terms of surgical techniques and preferences (open vs. MIS).

## MATERIALS AND METHODS

### 1. Study Participants

The AO Spine Knowledge Forum Degenerative developed an online questionnaire to determine surgeon treatment preferences for 3 unique L4–5 grade 1 DLS cases. No formal Institutional Review Board approval was required for this study. The survey was sent electronically to all AO Spine members between July 27 and September 8, 2023. All the participants signed a digital informed consent and agreed to use their anonymized answers for research purposes. Responses were excluded if participants chose multiple surgical options for each case.

### 2. Study Questionnaire

The study questionnaire collected demographic data of the participating surgeons including country and AO Spine region of practice, sex, age, years of practice in spine surgery, specialty, practice setting, spine surgery fellowship experience, and DLS surgical case volume. Participants were then presented with 3 representative clinical cases of L4–5 grade 1 DLS, each highlighting a unique constellation of pathological features with a clinical vignette and selected radiographic images. The cases included an elderly man with central stenosis without instability (case 1), a young female with bilateral foraminal stenosis and instability (case 2), and a middle-aged female with unilateral foraminal stenosis and mild instability (case 3). Participants were then asked to describe their preferred surgical technique for treating each case. They were asked if they would perform direct or indirect decompression as either the only procedure or a part of the overall procedure. If they chose to perform direct decompression, they could select one or more surgical approaches among open surgery or MIS. Subsequently, participants were asked if they would perform fusion and, if yes, through which technique. Open approaches were subdivided as decompression alone by means of laminotomy or laminectomy plus partial facetectomy, posterior instrumentation without interbody fusion (e.g., open decompression with pedicle screw fixation) or instrumented decompression with interbody fusion (i.e., open PLIF and unilateral or bilateral TLIF). Likewise, MIS approaches were defined as decompression alone (by means of laminotomy with tubular or specular/bladed retractors, or via uniportal or unilateral biportal endoscopy), posterior instrumentation without interbody fusion (e.g., MIS decompression with percutaneous pedicle screw fixation), and instrumented decompression with interbody fusion (i.e., unilateral or bilateral MIS-TLIF, endoscopic-assisted interbody fusion). Additionally, participants could also select among LLIF (either transpsoas or prepsoas with the use of cages with or without integrated screws/plates) or ALIF (using cages with or without integrated screws/plates) approaches. For this study, only answers pertaining to selection between open vs. MIS approaches were analyzed. The full questionnaire is available as a Supplementary Material.

### 3. Statistical Analysis

Categorical data were shown as absolute (n) and relative (%) frequencies. Statistical analysis of data was performed using the chi-square test. To ensure test validity, data groups were opportunely combined when values were lower than 1 and/or when more than 20% of the values were lower than 5. Multiple logistic regression was performed to investigate the associations between MIS and open surgery and AOSpine region, hospital setting, surgeon's age, years of surgical practice, case volume, specialty, fellowship, and patient's age. Open surgery (as defined above) was considered a negative outcome (encoded as "0"), whereas MIS (as defined above) as a positive outcome (encoded as "1"). The most frequent categories per each independent variable were selected as reference levels. Odds ratios (ORs) and 95% confidence intervals (CIs) were estimated for each reference category. Statistical significance was set at $p < 0.05$. Formal analysis was performed using Prism 10 (GraphPad Software Inc., La Jolla, CA, USA).

## RESULTS

A total of 943 surgeons responded, and 479 completed the survey. Participants were from North America (8.6%), Latin America (16.2%), Europe & Southern Africa (33.4%), Middle East & North Africa (10.9%), Asia Pacific (30.9%). Most surgeons were male (95.8%), aged between 35 and 44 (36.7%), and practicing for at least 5 years (76%). Most respondents were orthopaedic surgeons (62%); 39.9% practiced in an academic hospital, 32.4% in a private setting, and 25.3% in a public hospital. A little over half of the participants completed a postgraduate spine surgery fellowship (55.3%). Within this population, 30.9% of surgeons operated between 11 and 25 DLS cases per year, 30.5% operated between 26 and 50 DLS cases per year, and 14.2% operated between 51 and 100 DLS cases per year, with the remaining treating < 10 cases annually. The demographic characteristics of the survey respondents are summarized in Supplementary Table 1. Following the exclusion of multiple answers, cases 1, 2, and 3 eventually included 460, 460, and 465 responses, respectively (Fig. 1).

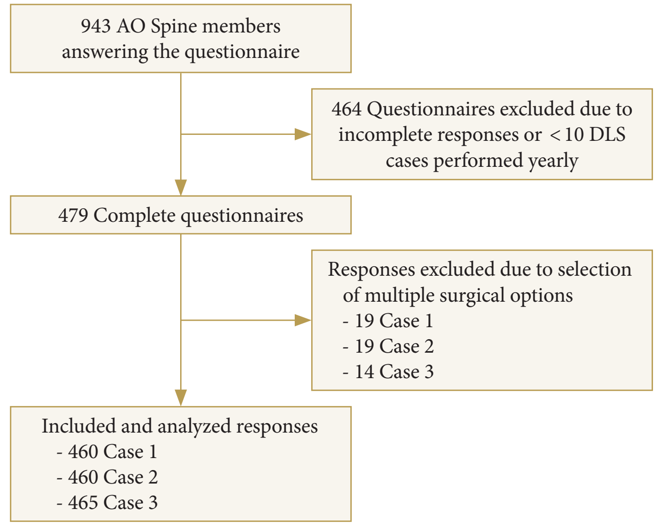


**Fig. 1.** Flow chart summarizing the inclusion of the survey's responses. DLS, degenerative lumbar spondylolisthesis.

### 1. Case 1 - Central Stenosis Without Instability in an Elderly Man

A retired 73-year-old male presents with 18 months of progressive pain radiating from the buttocks to the lower legs following a posterolateral distribution (left side worse than right side), with pain intensity reaching 7/10 at its worst. The patient had minimal LBP and leg pain was provoked by standing for long periods and walking. During his free time, the patient used to enjoy tennis, golf, and swimming, but symptoms interfered with these activities. He had a history of controlled hypertension and was a non-smoker. The physical exam revealed no motor deficits, reflexes were within normal limits, and paresthesias were located in the left foot and toe. Magnetic resonance imaging (MRI) and computed tomography (CT) showed L4–5 grade I DLS with central stenosis and a left-sided facet cyst. No significant instability was shown by lateral standing dynamic x-ray. No relevant sagittal imbalance nor spinopelvic parameter alteration was demonstrated at 36" standing films. For this case, 58.8% of respondents chose open surgery, 35.0% a MIS approach, 5.9% LLIF, and 0.3% ALIF (Table 1). Notable differences were found in surgical indications among different AO Spine regions (Table 2). Open surgery was the most common technique in all


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**Table 1.** Type of surgical decompression selected by participants for the proposed cases

| Type of surgery | Case 1 (n = 460) | Case 2 (n = 460) | Case 3 (n = 465) | p-value |
|---|---|---|---|---|
| Open | | | | < 0.001* |
| Decompression alone | 41 (8.9) | 8 (1.7) | 15 (3.2) | |
| Instrumented decompression without interbody fusion | 61 (13.3) | 48 (10.4) | 54 (11.6) | |
| PLIF | 55 (12.0) | 68 (14.7) | 44 (9.5) | |
| TLIF (unilateral or bilateral) | 113 (24.6) | 140 (30.5) | 84 (18.1) | |
| Total | 270 (58.8) | 264 (57.3) | 197 (42.4) | |
| MIS | | | | 0.148 |
| Decompression alone (tubular or specular/bladed retractor) | 45 (9.8) | 9 (2.0) | 17 (3.7) | |
| Instrumented without interbody fusion (tubular or specular/bladed retractor) | 7 (1.5) | 1 (0.2) | 13 (2.8) | |
| TLIF (unilateral or bilateral) | 85 (18.5) | 121 (26.3) | 124 (26.7) | |
| Endoscopic decompression alone | 11 (2.4) | 8 (1.7) | 14 (3.0) | |
| Endoscopic-assisted interbody fusion | 13 (2.8) | 11 (2.4) | 12 (2.6) | |
| Total | 161 (35.0) | 150 (32.6) | 180 (38.8) | |
| LLIF | 27 (5.9) | 39 (8.5) | 67 (14.4) | < 0.001* |
| ALIF | 2 (0.3) | 7 (1.6) | 13 (2.8) | 0.016* |
| Conservative treatment | 0 (0) | 0 (0) | 8 (1.7) | - |

Values are presented as number (%).
PLIF, posterior lumbar interbody fusion; TLIF, transforaminal lumbar interbody fusion; MIS, minimally invasive surgery; LLIF, lateral lumbar interbody fusion; ALIF, anterior lumbar interbody fusion.
*p < 0.05, statistically significant differences.

**Table 2.** Type of surgical approach for case 1 across different AO Spine regions

| Type | Europe & Southern Africa | Asia-Pacific | North America | Middle East & Northern Africa | Latin America | p-value |
|---|---|---|---|---|---|---|
| Open | 87 (56.5) | 89 (61.4) | 26 (66.7) | 30 (58.8) | 38 (53.5) | 0.210 |
| MIS† | 52 (33.8) | 50 (34.5) | 6 (15.4) | 21 (41.2) | 32 (45.1) | 0.025* |
| LLIF‡ | 13 (8.4) | 6 (4.1) | 7 (17.9) | 0 (0) | 1 (1.4) | 0.014* |
| ALIF | 2 (1.3) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | - |

Values are presented as number (%).
MIS, minimally invasive surgery; LLIF, lateral lumbar interbody fusion; ALIF, anterior lumbar interbody fusion.
*p < 0.05, statistically significant differences. †These include both MIS (bladed/specular or tubular) and endoscopic approaches. ‡Middle East & Northern Africa were excluded from the analysis.

5 regions (Europe & Southern Africa: 56.5%; Asia-Pacific: 61.4%; North America: 66.7%, Middle East & Northern Africa: 58.8%; Latin America: 53.5%); followed by MIS (Europe & Southern Africa: 33.8%; Asia-Pacific: 34.5%; North America: 15.4%, Middle East & Northern Africa: 41.2%; Latin America: 45.1%), and LLIF (Europe & Southern Africa: 8.4%; Asia-Pacific: 4.1%; North America: 17.9%, Middle East & Northern Africa: 0.0%; Latin America: 1.4%). The different distribution of MIS and LLIF surgeries among AO Spine regions was statistically significant ($p = 0.025$ and $p = 0.014$). Conversely, ALIF was performed only by 1.3% of practitioners in the sole Europe & Southern Africa area.

### 2. Case 2 - Bilateral Foraminal Stenosis With Instability in a Young Female

A 48-year-old female cashier presents with progressive LBP and bilateral leg pain radiating from the buttocks to mid-calf in posterolateral distribution over the previous 5 years. Axial LBP was constant, with an intensity ranging between 5–10 out of 10, and worse with changing positions and standing. Leg pain was graded 10/10, predominantly located on the right side rather than the left side, triggered by standing and walking, and tend-

**Table 3.** Type of surgical approach for case 2 across different AO Spine regions

| Type | Europe & Southern Africa | Asia-Pacific | North America | Middle East & Northern Africa | Latin America | p-value |
|---|---|---|---|---|---|---|
| Open | 94 (60.3) | 82 (57.3) | 16 (42.1) | 31 (64.6) | 41 (54.7) | 0.249 |
| MIS[†] | 43 (27.6) | 54 (37.8) | 7 (18.4) | 17 (35.4) | 29 (38.6) | 0.086 |
| LLIF[‡] | 16 (10.3) | 6 (4.2) | 14 (36.8) | 0 (0.0) | 3 (4.0) | < 0.001* |
| ALIF | 3 (1.9) | 1 (0.7) | 1 (2.6) | 0 (0.0) | 2 (2.7) | - |

Values are presented as number (%).
MIS, minimally invasive surgery; LLIF, lateral lumbar interbody fusion; ALIF, anterior lumbar interbody fusion.
*p < 0.05, statistically significant differences. †These include both MIS (bladed/specular or tubular) and endoscopic approaches. ‡Middle East & Northern Africa were excluded from the analysis.

ed to resolve with sitting or lying down. The patient also complained about numbness in bilateral feet after standing for more than 30 minutes. At the clinical exam, she had no motor deficits, reflexes were within normal limits, and paresthesia in the left great toe. Grade 1 DLS at L4–5 with bilateral foraminal stenosis more severe at the right foramen was shown at MRI and CT. Dynamic x-ray imaging demonstrated segmental instability with a 5-mm anterior translation in flexion. No relevant sagittal imbalance nor spinopelvic parameter alteration was shown at 36” standing films. For this case, 57.3% of respondents chose open surgery, 32.6% MIS, 8.5% LLIF, and 1.6% ALIF (Table 1). Statistically significant differences emerged only when comparing LLIF distribution among different AO Spine regions (p < 0.001, Table 3). Open surgery was the most common technique in all 5 regions (Europe & Southern Africa: 60.3%; Asia-Pacific: 57.3%; North America: 42.1%; Middle East & Northern Africa: 64.6%; Latin America: 54.7%), whereas MIS was the second most common in Europe & Southern Africa (27.6%), Asia-Pacific (37.8%), Middle East & Northern Africa (35.4%), and Latin America (28.9%) regions. Conversely, LLIF was significantly more popular in North America (36.8%), and ALIF was performed only by a minority of participants ( < 3%).

### 3. Case 3 - Unilateral Foraminal Stenosis With Mild Instability in a Middle-Aged Female

A 64-year-old female administrative assistant presents with LBP and radicular pain in the right leg from the buttock to the ankle in a posterolateral distribution. The pain began in bilateral legs but then became right leg predominant. Axial LBP was considered equal to leg pain and was rated 10/10 with walking. Leg pain initially occurred only with ambulation but subsequently occurred when lying in bed for the previous 3 months. The patient has been using a cane for the past 3 months. At the clinical exam, right hip flexion, knee extension and knee flexion were rated 4/5 (pain limited), right foot dorsiflexion and extensor hallucis longus 4+/5, and plantar flexion was 5/5.

The motor exam in the left leg was normal. The patient reported numbness to light touch and sharps over the right lateral calf and dorsal surface of the foot. Reflexes were within normal limits. MRI showed grade 1 DLS at L4–5 with right foraminal stenosis and bilateral facet joint effusion. Dynamic x-ray imaging demonstrated slight segmental instability with a 3-mm anterior translation in flexion. No relevant sagittal imbalance was shown at 36” standing films. For this case, 42.4% of respondents chose open surgery, 38.8% MIS, 14.4% LLIF, 2.8% ALIF, and 1.7% suggested to proceed with conservative treatment (Table 1). No statistically significant difference was found in terms of surgical indication among all AO regions, except for LLIF, which was significantly more common among North American surgeons (p = 0.0004, Table 4). For this case, open surgery was the most preferred approach in Europe & Southern Africa (40.1%), North America (41.5%), and Middle East & Northern Africa (56.0%), while MIS was more popular in the Asia-Pacific (42.9%) and Latin America (42.9%) regions. As anticipated above, LLIF was performed more frequently by North American participants (29.3%), while ALIF was again carried out only in a minority of cases.

### 4. Summary of Results and Multivariate Logistic Regression

When grouping surgical approaches by case (Table 1), open surgery was the most preferred approach in all 3 cases (58.8%, 57.3%, and 42.4%, respectively), although it was significantly less common in case 3 (p < 0.001). MIS was the second most popular approach (35.0%, 32.6%, and 38.8%, respectively). Overall, 38.7% and 24.0% utilized open and MIS approaches in all 3 cases, respectively, whereas the remaining surgeons chose different techniques based on the single case.

In case 1, the use of MIS was significantly less common among surgeons aged between 55 and 64 years (OR, 0.33; 95% CI, 0.22–0.94; p = 0.041) and practicing for 11–15 years (OR, 0.41; 95%


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**Table 4.** Type of surgical approach for case 3 across different AO Spine regions

| Type | Europe & Southern Africa | Asia-Pacific | North America | Middle East & Northern Africa | Latin America | p-value |
|---|---|---|---|---|---|---|
| Open | 63 (40.1) | 57 (40.7) | 17 (41.5) | 28 (56.0) | 32 (41.6) | 0.259 |
| MIS† | 57 (36.3) | 60 (42.9) | 11 (26.8) | 19 (38.0) | 33 (42.9) | 0.353 |
| LLIF | 30 (19.1) | 18 (12.9) | 12 (29.3) | 0 (0.0) | 7 (9.1) | < 0.001* |
| ALIF | 4 (2.5) | 2 (1.4) | 0 (0) | 2 (4.0) | 5 (6.4) | - |
| Conservative | 3 (2.0) | 3 (2.1) | 1 (2.4) | 1 (2.0) | 0 (0) | - |

Values are presented as number (%).
MIS, minimally invasive surgery; LLIF, lateral lumbar interbody fusion; ALIF, anterior lumbar interbody fusion.
*p < 0.05, statistically significant differences. †These include both MIS (bladed/specular or tubular) and endoscopic approaches.

CI, 0.18-0.94; p = 0.038). Interestingly, MIS was also significantly more popular among neurosurgeons (OR, 1.73; 95% CI, 1.12–2.70; p = 0.014). Similarly, surgeons aged between 55-64 years were less likely to perform MIS for case 2 (OR, 0.30; 95% CI, 0.10–0.87; p = 0.030), which was more commonly preferred by neurosurgeons (OR, 2.59; 95% CI, 1.66–4.09; p < 0.001). MIS was significantly less utilized among participants who did not complete a fellowship (OR, 0.50; 95% CI, 0.28–0.89; p = 0.012). In case 3, only surgeons aged between 55 and 64 years were less likely to utilize MIS (OR, 0.34; 95% CI, 0.12–0.92; p = 0.038). All the associations are shown in Supplementary Table 2.

## DISCUSSION

The results of this global cross-sectional survey study highlighted the current trends and preferences amongst AO Spine surgeons regarding the treatment of grade 1 L4–5 DLS with open versus MIS spine surgery. The data underscore significant regional variations and demographic influences on the choice of surgical techniques. Open surgery was the most commonly preferred approach for all 3 clinical cases, particularly in cases 1 and 2, which featured central and bilateral foraminal stenosis. This preference aligns with the historical predominance of open surgery for achieving a thorough decompression and reliable arthrodesis in DLS cases characterized by extensive stenosis. The high prevalence of open surgery (58.8% for case 1, 57.3% for case 2) across diverse regions suggests a continued reliance on its perceived efficacy and familiarity among surgeons.[11]

MIS approaches were the second most common choice, especially in case 3 (38.8%), involving unilateral foraminal stenosis with mild instability. The surgeons' preference for MIS reflect a view that it can reliably and adequately address unilateral foraminal stenosis with mild instability.[12] It may also reflect the perception of many surgeons that MIS has limitations in achieving wide central decompressions and addressing long-term spinal instability via arthrodesis. Smaller incisions and surgical corridors, as well as decreased bony exposures, are features of MIS surgery that limit collateral tissue damage but can also restrict the extent of decompression and bone surface available for fusion. A meta-analysis by Lu et al.[10] revealed that MIS fusion for grade I and II DLS resulted in significantly less blood loss and length of stay, although no significant differences in terms of functional outcome measures emerged. Similarly, a more recent study from Qin et al.[13] specifically comparing open vs. MIS-TLIF in the treatment of single-level DLS confirmed similar results, although the latter was associated with better long-term Oswestry Disability Index scores. Nonetheless, the existence of an actual difference in long-term functional outcomes between the 2 techniques is still debated.[14]

Interestingly, MIS was significantly more popular among younger surgeons and those who completed a spine surgery fellowship, which may be related to 2 important aspects. First, younger spine surgeons are increasingly exposed to newer MIS procedures and MIS-related technology, including navigation,[15] endoscopy,[16] and robotics,[17] which may increase their familiarity and comfort with these techniques. However, due to the need for specific equipment, limited surgical exposure, and restricted tactile feedback, MIS is also characterized by a steeper learning curve with a higher complication rate during that time that is estimated to be about 32–44 cases.[18] After that learning curve is incorporated into surgeons' training, there may be fewer concerns about potential complications when coupled with the supervision by senior surgeons. It may explain why fellowship-trained surgeons, which likely have a facilitated exposure to MIS techniques, showed a higher preference towards these approaches. In a recent systematic review, training during residency/fellowship was considered among the 5 most important factors in gaining MIS proficiency.[19]

Surgeon age and years of practice were notable factors influencing the choice of surgery. Surgeons aged 55–64 years and those practicing for 11–15 years were less likely to opt for MIS. This trend could be due to greater comfort with open techniques acquired over years of practice or that older surgeons had less exposure to MIS during their training. Neurosurgeons, on the other hand, demonstrated a higher propensity for MIS than orthopaedic spine surgeons.[20]

The study survey revealed significant regional differences in the adoption of surgical techniques. For instance, LLIF was significantly more common in North America, while MIS was preferred in the Asia-Pacific and Latin American regions. These differences may be attributed to regional training programs, surgical technology availability, patient preferences, industry influence, healthcare infrastructures, culture, and reimbursement policies. Similar outcomes were reported by a recent global survey, which demonstrated that MIS was considered the mainstream spine surgery among surgeons in Asia and South America, while North America showed the lowest rate of MIS implementation globally.[21] However, it must be noted that the North American response rate was very low in this study, and this data may likely be skewed toward the small number of surgeons who favor open surgery. Thus, our data on MIS preferences in North American surgeons may not accurately represent the real-world practice patterns in North America. The findings of this study have several important implications for clinical practice and future research. The persistent preference for open surgery highlights the need for continued evaluation of its outcomes compared to MIS, particularly in complex DLS cases. Additionally, the growing acceptance of MIS calls for standardized training protocols to ensure consistency during adoption and that both radiographic and clinical outcomes are equivalent or superior to analogous to open procedures. The regional differences in surgical preferences suggest that tailored guidelines and resource allocation could enhance the effectiveness and accessibility of spine care globally. Moreover, ongoing educational initiatives are crucial as technology continues to evolve. This should be complemented by rigorous research to objectively evaluate new techniques and technologies, ensuring their potential benefits are thoroughly assessed.

This study has some limitations. While providing valuable insights, it is limited by its reliance on self-reported data, which may introduce response bias. Future research should aim to corroborate these findings with clinical outcome data and explore the long-term efficacy of open versus MIS approaches. Nonetheless, some geographical regions (especially North America) were significantly less represented than others (e.g., Europe & Southern Africa and Asia-Pacific). The limited data could significantly skew the results towards the small sample of surgeons who answered the questionnaire. Therefore, a more comprehensive survey of these underrepresented areas should be performed to grasp their actual surgical practice and increase the generalizability of our results. In addition, as a cross-sectional study, this investigation cannot impute any causality nor assess any change of practice over time.

## CONCLUSION

This global survey provides valuable insight into the current landscape and trends in the current landscape of surgical preferences for treating grade 1 L4–5 DLS. The predominance of open surgery, the increasing adoption of MIS, and the significant regional and demographic influences underscore the dynamic nature of this specific field. These insights can guide future research, clinical guidelines, and educational programs to optimize surgical care for DLS.

## NOTES

**Supplementary Materials:** Supplementary Materials and Supplementary Tables 1-2 for this article is available at https://doi.org/10.14245/ns.2448902.451.

**Conflict of Interest:** The authors have nothing to disclose.

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