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Patient-reported outcomes and their associated factors at 1- and 2-year follow-up after lumbar spine surgery: A surgery registry study

ABSTRACT

Purpose Degenerative lumbar conditions are a leading cause of disability worldwide, often requiring surgery when conservative treatments fail. Data on surgical outcomes from patients' perspectives and influencing factors remain limited. This study aimed to assess 1-year and 2-year Patient-Reported Outcomes (PROs) following lumbar spine surgery and identify factors associated with these outcomes.

Methods This surgery registry study included 1,195 adult patients who underwent lumbar spine surgery between 2017 and 2022 at a tertiary hospital in Singapore. Patients completed the EQ-5D-3L and Oswestry Disability Index before surgery, and one year (n=741) and two years (n=440) after surgery. Multivariable logistic regression identified factors influencing PRO improvements at the dimension level.

Results The mean age of the patients was 58.1 years (SD 16.1). From baseline to 1-year, patients experienced the largest improvements in pain/discomfort (δ = 0.55–0.56) and social functioning (δ = 0.48–0.53), while improvements in ADLs and functional tasks were smaller, with negligible change in lifting (δ = 0.04); these effects largely persisted at 2 years. Patients with poorer baseline PROs consistently improved across all PROs at 1 year. Higher education and conditions affecting only the L4/5 spinal level were associated to better outcomes in activities of daily living, pain/discomfort, and social functioning. Higher education and prolapsed disc diagnosis were associated with functional task improvements. At 2 years, poorer baseline PROs remained influential, while the absence of comorbidities emerged as a significant factor.

Conclusions Substantial improvements in pain and social domains occurred within the first year and persisted to year two, while physically demanding tasks such as lifting remained difficult to restore. Patients with poorer baseline PROs and higher education derived the greatest benefit, emphasising tailored pre-operative interventions to optimise outcomes.

Keywords Patient-centred care; patient-reported outcome; degenerative lumbar conditions; lumbar surgery

Plain English summary

This study investigated the outcomes of lumbar spine surgery in 1,195 patients in Singapore. Significant improvements in patient-reported outcomes (PROs), such as pain reduction and improved social function, were observed within the first year after surgery, with limited further improvement in the second year. Higher education and conditions affecting only the L4/5 spinal level were associated to better outcomes in activities of daily living, pain/discomfort, and social functioning. Higher education and prolapsed disc diagnosis were associated with functional task improvements. At 2 years, poorer baseline PROs remained influential, while the absence of comorbidities emerged as a significant factor. These findings emphasize the importance of pre-operative assessments and patient education to optimize surgical outcomes.

Introduction

Degenerative lumbar conditions are a major cause of disability worldwide, affecting approximately 266 million people, or 3.63% of the global population [1]. The broad range of symptoms complicates their identification, diagnosis, and treatment [2-4]. International clinical guidelines usually recommend a conservative treatment approach initially, as non-surgical interventions resolve most cases within three months. While guidelines acknowledge that lumbar surgery can outperform conservative treatment, it is not always the first choice due to risks and the uncertainty of which patients benefit most from non-operative methods [2-4]. Therefore, surgery is considered a secondary option, specifically for cases where thorough diagnostic evaluations confirm its necessity and when symptoms persist for more than 12 weeks despite conservative management.

With the growing emphasis on patient-centred care in lumbar spine surgery [5], clinicians increasingly value patient-reported outcomes (PROs) alongside traditional epidemiological measures in clinical decision-making [6, 7]. PRO measures, or PROMs, are validated methods used to assess patient-reported functionality, measure outcomes, and evaluate recovery [5]. Reviews consistently show significant improvements in postoperative PRO scores following lumbar spine surgery [8, 9]. Several major cohorts, including the Spine Patients Outcome Research Trial (SPORT), the Canadian Spine Outcome Research Network (CSORN), and the Swedish National Register for Lumbar Spinal Surgery, have reported significant improvements in PROs up to one year post-surgery [10-12], with benefits persisting into the second year [13-17]. However, much of the data from these cohorts were collected over a decade ago, which may not reflect current surgical practices [11]. Additionally, these studies were mostly conducted in Western countries, limiting their applicability to Asian populations. The only study from Asia involved a small sample size, further limiting the comparability of its findings [18].

A recent review also identified baseline PROs and various socio-economic factors as valuable predictors of post-operative disability and PROs [19]. While evidence consistently shows that patients with severe baseline PROs often improve following surgery [12, 20-22], findings on other factors remain mixed, including gender [12, 23], age [12], education level [23-25], ethnicity [12, 20], presence of comorbidities [12, 21, 26], and body mass index [27]. Only four studies have examined clinical variables related to different lumbar conditions [12, 20, 28, 29], and only one has investigated the spine level involvement [30], revealing a significant gap in research on these factors. Most existing studies are from Western countries, and their findings may not apply to Asia due to the subjective nature of PROs, which are influenced by language, culture, and lifestyle.

Given the identified research gaps, this study aims to (1) determine 1-year and 2-year PROs at both the individual dimension and overall levels for patients with degenerative lumbar conditions following surgery, and (2) investigate factors associated with improvements in PROMs at these intervals in Singapore, a multi-ethnic and multicultural city-state in Southeast Asia.

Methods

Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Domain Specific Review Board, National Healthcare Group, Singapore (Date 21 January 2021/DSRB 2020/01075). We reported the study following the REporting of Studies Conducted Using Observational Routinely-Collected Health Data (RECORD) and Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (Table S1) [31, 32].

Study design, setting, and data collection

This surgery registry study analysed data from patients enrolled in the Spinal Surgery Registry at the Spine Centre, National University Hospital (NUH), a university-affiliated tertiary healthcare facility in Singapore. We screened all patients who underwent primary elective lumbar spine surgery for degenerative lumbar conditions, with or without lower limb radicular symptoms, from 2017 to 2022. Eligible patients were prospectively enrolled into an institutional review board-approved longitudinal cohort. Study data were collected and managed using REDCap electronic data capture tools hosted at NUH [33, 34]. REDCap (Research Electronic Data Capture) is a secure, web-based software platform designed to support data capture for research studies, providing 1) an intuitive interface for validated data capture; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for data integration and interoperability with external sources.

All enrolled patients first underwent a physiotherapy trial lasting up to three months before considering surgery. Surgery was indicated for persistent symptoms despite physiotherapy, progressive neurological deterioration, or worsening deformity. Patients underwent procedures such as microdiscectomy, decompression laminectomy, and instrumented fusions. The division of spine surgery, comprising over five fellowship-trained spine surgeons, routinely conducts pre-operative audits to review surgery indications and determine the most appropriate procedure.

After obtaining informed consent, a trained staff member from the NUH Spine Centre collected PRO data using three questionnaires: the EQ-5D-3L, the Short Form 36 Health Survey (SF-36), and the Oswestry Disability Index (ODI). Patients completed these questionnaires at surgery enlistment for pre-operative assessment and during follow-up visits at 3-6 months, one year, and two years post-surgery.

If patients missed an appointment or returned an incomplete questionnaire, the staff contacted them to ensure data completeness.

Eligibility criteria

The cohort included patients who met the following criteria: 1) a clinical diagnosis of stenosis, prolapsed disc, spondylolisthesis, and degenerative disc disease; 2) underwent lumbar spine surgeries, such as microdiscectomy, decompression laminectomy, or instrumented fusion, at the Spine Centre of the tertiary hospital between 1 January 2017 and 31 July 2022; and 3) had PROs assessed both pre- and postoperatively with complete data documentation.

PROMs

The EQ-5D-3L is a generic health status measure developed by the EuroQol Group that covers five dimensions of health-related quality of life: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression [35]. Each dimension has a three-point response scale (no problems, moderate problems, extreme problems). An EQ index score reflects respondents' overall health utility based on their responses to the five dimensions. The index ranges from -0.769 (worse than death) to 1 (full health) [36], with higher scores indicating better health status. Additionally, a visual analogue scale (EQ VAS) asks respondents to rate their health from 0 (worst imaginable health) to 100 (best imaginable health). The EQ-5D-3L was selected because it was routinely collected in our spine registry during the study period and remains widely used in clinical practice. While the 5L version provides increased sensitivity, the 3L version has demonstrated adequate validity, responsiveness, and feasibility in patients undergoing spine surgery [37, 38].

The ODI assesses disability caused by spinal diseases.[39] It contains ten items (pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and travelling), each measuring disability in a different domain on a six-point response scale. An ODI score can be calculated, ranging from 0% (no disability) to 100% (maximum disability). The ODI has demonstrated strong psychometric properties in assessing patients undergoing lumbar disc surgery [40].

Outcome and exploratory variables

PROs were the outcome variables, defined as the outcomes measured by individual items and scales of the PROMs. Each item of the EQ-5D and ODI was considered a specific PRO, totalling 15 PROs: five from the EQ-5D and ten from the ODI. These were grouped into five categories: 1) activities of daily living (ADLs) (mobility, walking, self-care, personal care); 2) functional tasks (lifting, sleep, sitting, standing); 3) mental health (anxiety/depression); 4) pain or discomfort (pain/discomfort, pain intensity); and 5) social functioning (usual activities, social life, travelling, sex life). As each PROM used a Likert-type response scale, the raw PRO data were converted into binary outcomes to indicate whether the PROs improved (yes/no) from baseline to 1- and 2-years post-surgery. This approach was selected to enhance clinical interpretability and reduce model complexity given the ordinal structure of the data and small cell counts across multiple response levels.

Baseline patient socio-demographics and medical comorbidities were documented, and clinical data were obtained from medical records and linked to the PRO data. This included comorbidities, BMI, clinical diagnosis, type of surgery, and spine level. The study focused on nine key exploratory variables: baseline PROs (moderate vs severe), gender (male vs female), age (older adults (≥65) vs younger adults (<65, including young and middle-aged)), ethnicity (Chinese vs non-Chinese; Malay and Indian were grouped as non-Chinese to ensure sufficient sample size given Singapore's demographics of ~74% Chinese, 13% Malay, and 9% Indian), BMI (normal vs overweight/obese), education level (college, diploma, university vs primary and secondary), comorbidities (presence vs absence), diagnosis (spondylolisthesis vs degenerative disc disease vs prolapsed disc vs stenosis vs non-specific pathologies), and spine level. Spine level was classified into five groups: mixed level (involving more than one segment), L4/S1 (two-level surgeries spanning L4/5 and L5/S1), L4/5 only, L5/S1 only, and others (e.g., L2/3 or L3/4). For the five EQ-5D PROs, the response options of "no problems", "some/moderate problems", and "extreme/unable" were coded as no, moderate, and severe, respectively. For the ten ODI PROs, the six-point response levels were coded into three levels: no (level 1), moderate (level 2 or 3), and severe (level 4, 5, or 6).

Statistical analysis

Descriptive statistics were used to present the socio-demographic and clinical variables of the patients, as well as their PROs at both dimensional and overall levels. Mean and standard deviation, or median and interquartile range, were reported for continuous variables, while counts and percentages were used for categorical variables. EQ-5D index, EQ-VAS, and ODI scores were summarised using means and standard deviations at baseline, 1 year, and 2 years. Paired *t*-tests were conducted among participants with complete data at both timepoints to assess within-person changes. For each PRO item, we calculated the proportion of individuals with pre-operative problems who showed improvement, defined as a shift to a better response, at one- and two-years post-surgery. Cliff's delta (δ) was computed to quantify the magnitude and direction of change, interpreted as negligible (<0.14), small (0.14–0.33), medium (0.33–0.47), or large (≥0.47) [41].

Patients who reported "no problems" at baseline were excluded from each outcome analysis, as no improvement was expected in these groups. Fisher's exact tests were used to explore associations between each exploratory variable and binary improvement outcomes. Univariate logistic regressions were then conducted within each imputed dataset to identify candidate predictors. Variables with a *p*-value <0.05 and deemed clinically relevant were selected for multivariable modelling.

For each PRO, multivariable logistic regression models were constructed using backward elimination [42], with a *p*-value threshold of <0.05 for variable retention. Analyses were performed separately for one- and two-year post-surgery outcomes to capture temporal differences in PRO improvement. Complete-case analysis was conducted as the primary analytical approach to enable full assessment of model fit and regression diagnostics. Statistical significance was set at a two-sided p-value <0.05, with no adjustment for multiple comparisons, given the exploratory nature of the analysis and the potential for overcorrection to increase Type II error. Multicollinearity was assessed using variance inflation factors (VIF) and tolerance statistics; VIF values ≤0.2 or ≥5.0, or tolerance values <0.1, indicated collinearity and prompted further review. Model fit was evaluated using the Hosmer–Lemeshow goodness-of-fit test and the Pregibon link test. A non-significant p-value (p > 0.05) from the Hosmer–Lemeshow test indicated adequate goodness-of-fit, while a non-significant squared predicted value (hat^2, p > 0.05) from the link test suggested correct model specification.

To assess potential attrition bias, we compared baseline socio-demographic, clinical characteristics, and PROs between patients who completed follow-up and those lost to follow-up. To further examine the robustness of our findings, multiple imputation by chained equations (MICE) was performed as a sensitivity analysis, assuming data were missing at random [43]. Twenty imputed datasets were generated using ordered logistic regression. Socio-demographic and clinical predictors were included in the imputation model. Passive imputation was applied to derive change scores (follow-up minus baseline) and to generate binary indicators of improvement. All multivariable models were then refitted using the mi estimate procedure, and pooled estimates were reported using Rubin's rules. All analyses were conducted using Stata version 18.0 (StataCorp, College Station, TX, USA).

Results

Socio-demographic and clinical characteristics

A total of 1,195 patients underwent surgery and completed baseline PROMs (Figure 1). Table I presents the baseline characteristics of this cohort. The mean age was 58.1 years (standard deviation [SD] = 16.1), with 57.6% being under 65 years of age. Most patients were male (51.5%), of Chinese ethnicity (70.3%), and had completed primary or secondary education (51.4%). The mean BMI of the patients was 26.3 kg/m² (SD = 4.7), and 44.6% reported having comorbidities. The most common diagnosis was stenosis (40.5%), followed by prolapsed disc (22.9%) and spondylolisthesis (19.8%). The lumbar region was the most commonly affected spine level, with L4/5 being the most frequently involved specific level (36.6%).

Of the 1,195 patients at baseline, 741 completed the 1-year follow-up, and 440 completed the 2-year follow-up. The distribution of socio-demographic and clinical characteristics was comparable between the first- and second-year follow-up periods. Table II presents the outcome categories and the improvements in PROs among individuals with baseline PRO problems at different time points.

PROs at 1- and 2-years after lumbar surgery

Most patients with pre-operative PRO problems experienced significant improvements following lumbar surgery (Table II). From baseline to 1-year follow-up, individuals with problems in pain intensity ($\delta = 0.56$) and pain/discomfort ($\delta = 0.55$) experienced large improvements. Large effects were also observed in social functioning domains such as travelling ($\delta = 0.53$), sex life ($\delta = 0.48$), and social life ($\delta = 0.48$). In contrast, improvements in ADLs were generally moderate, with Cliff's delta ranging from 0.33 to 0.45, except for self-care ($\delta = 0.22$), which showed a small effect size. Mental health (anxiety/depression) showed a moderate effect ($\delta = 0.34$). Improvements in functional tasks such as sitting ($\delta = 0.34$), standing ($\delta = 0.52$), and sleeping ($\delta = 0.32$) were moderate to large. Lifting ($\delta = 0.04$), however, showed negligible improvement, despite 46.9% of patients reporting better function.

These patterns largely persisted at the 2-year follow-up, with 56.4%–86.7% of patients continuing to report improvement across domains. Effect sizes remained stable, with pain intensity ($\delta = 0.59$) and pain/discomfort ($\delta = 0.53$) sustaining large effects, and social functioning domains continuing to show large improvements. Functional domains such as lifting ($\delta = 0.04$) again showed negligible change, while ADLs and mental health remained in the small-to-moderate range. Notably, 90.7% (399/440) of patients completed both the 1- and 2-year follow-up assessments. Consistent with these domain-level findings, the EQ-5D index, EQ VAS, and ODI total scores improved significantly from baseline to 1 year, with minimal further gains up to 2 years (Figure 2). Paired t-tests showed significant improvements from baseline: EQ-5D increased by 0.33 (95% CI: 0.30 to 0.36) at 1 year and 0.32 (0.29 to 0.36) at 2 years; EQ-VAS increased by 6.83 (5.44 to 8.21) and 5.38 (3.55 to 7.22); ODI decreased by –23.36 (–25.07 to –21.65) and –24.41 (–26.45 to –22.37) ($p < 0.001$ for all) (Table S2).

Factors associated with improvements in PROs in univariate analysis

Tables S3-6 show the factors associated with improvements in PROs based on univariate analysis. At the 1-year follow-up, poorer baseline PROs were consistently associated with improvements in almost all PROs, except for walking, self-care and personal care. Other significant factors included education, comorbidities, and spine levels for ADLs; education and diagnosis for functional tasks; education for mental health and pain/discomfort; and age, education, comorbidities, and spine levels for social functioning. At the 2-year follow-up, baseline PROs and comorbidities remained associated with improvements in ADLs and social functioning, while only baseline PROs were consistently associated with functional tasks, mental health, and pain/discomfort.

Factors associated with improvements in PROs in multivariable analysis

Table III and Tables S6-9 show the factors associated with improvements in PROs based on multivariable logistic regression analysis. At the 1-year follow-up, several key factors were consistently associated with greater odds of improvement across different PRO categories. For ADLs, poorer baseline PROs (ORs: 1.80–9.30), younger age (ORs: 1.87–3.15), and Chinese ethnicity (ORs: 1.73–2.13), higher education (ORs: 2.35–3.67) were significantly associated with higher odds of improvement. For social functioning, poorer baseline PROs (ORs: 2.45–19.1), higher education (ORs: 2.57–3.52), and L4/5 spine level conditions were significant factors for improvement in all PROs.

Regarding functional tasks, poorer baseline PROs (ORs: 2.12–4.84), higher education (ORs: 1.68–2.53), and a diagnosis of prolapsed disc were associated with improvements in nearly all PROs. In terms of mental health, patients with higher education had greater odds of improvement in anxiety or depression (OR: 1.94). Similarly, patients with poorer baseline PROs (ORs: 4.82–21.5) and higher education (ORs: 2.23–2.59) were more likely to report improvement in pain/discomfort.

Some key factors for improvements observed in the first year persisted into the second year. At the 2-year follow-up, patients with poorer baseline PROs continued to show significant improvements in all PROs for functional tasks (ORs: 2.01–5.54), anxiety/depression (ORs: 3.08–23.7), and social functioning (ORs: 2.84–7.20). Similarly, younger age was associated with sustained improvements in walking/mobility (ORs: 2.21-2.59) and lifting (OR: 2.10). A notable difference was the emergence of comorbidities as a significant factor, with patients without comorbidities showing higher odds of improvement in some ADLs, such as mobility and self-care (ORs: 2.62–3.21), pain/discomfort (OR: 2.20), and social functioning (ORs: 1.96–3.96).

Model diagnostics indicated acceptable fit in almost all multivariable models, with non-significant Hosmer–Lemeshow and Pregibon link test results ($p > 0.05$), suggesting good calibration and correct specification. No evidence of multicollinearity was observed (Tables S7–S10). Findings from the imputed regression models were consistent with those from the complete-case analysis (Tables S11–S14).

Discussion

This study found significant improvements in overall PROs from baseline to the 1-year follow-up, with a plateau observed at 2 years. Poorer baseline PROs, higher education, a diagnosis of prolapsed disc, and L4/5 spinal level conditions were associated with 1-year improvements in PROs. By the 2-year mark, poorer baseline PROs remained influential, with the absence of comorbidities also emerging as a significant factor.

Consistent with previous studies in the USA and Australia [13-16], the greatest improvements occurred within the first-year post-surgery The initial 3- to 6-month period may be affected by tissue healing from surgical (iatrogenic) trauma, which may not accurately represent the true efficacy of the surgery [44]. By the 1-year mark, these effects usually subside, making this time point optimal for assessing the true impact of lumbar spine surgery without the influence of natural biological healing processes [45]. The sustained positive effects at two years indicate both the initial success and long-term efficacy of the surgery in managing underlying conditions. This continued improvement may result from ongoing rehabilitation, patient compliance, and resolution of the underlying issue. As one of the few studies examining PROs in lumbar spine surgery in Asia—where socio-cultural factors differ significantly—this study confirms previous findings from larger registry cohorts. Future research should examine outcomes beyond two years to understand the mid- to long-term effects of these surgeries in diverse Asian populations [16, 17].

Our study is among the few to report domain-level improvements in PROs following lumbar surgery, particularly within a multi-ethnic Asian cohort. While improvements in pain/discomfort (δ = 0.55–0.59) are consistent with prior evidence showing that surgical interventions offer substantial relief from radicular and nociceptive symptoms [10, 11], our finding of large and sustained improvements in social functioning, specifically in travelling, sex life, and social life (δ = 0.48–0.53), adds a novel and underexplored dimension to patient recovery. These domains are rarely reported independently in the literature, despite being critical to patients' lived experiences. However, the interpretation of these findings should be tempered by the possibility of reporting bias, particularly in culturally sensitive areas such as sex life, where disclosure may be influenced by social norms. Moreover, differences in cultural perceptions of health, modesty, and recovery may shape how patients respond to items on social functioning. Improvements in social functioning may also reflect a broader recovery of confidence, mobility, and autonomy, driven by reduced pain and increased participation in previously avoided activities [46]. The durability of these gains at two years suggests lasting reintegration into social roles, with potential spillover benefits for mental well-being and quality of life [47, 48]. Our findings underscore the value of including social domains in outcome measurement and support rehabilitation approaches that address not only physical function but also patients' return to meaningful social engagement.

Our study highlights the value of focusing on specific PROs rather than overall scores, an approach that offers detailed insights into the recovery of different functions within a multi-ethnic Asian cohort. This is particularly important for physically demanding tasks like lifting, which showed negligible improvement ($\delta = 0.04$) despite nearly half of patients reporting gains, suggesting that physically demanding tasks remain resistant to surgical recovery. Lifting requires significant strength, coordination, and stability, which are harder to regain, particularly for those with comorbidities or prolonged symptoms. The difficulty in improving 'lifting' tasks may result from greater physical demands compared to simpler postures like sitting or standing. Variability in improvement could also be due to differences in rehabilitation adherence, tissue recovery, and surgical invasiveness [49, 50]. Conversely, most patients showed significant improvement in personal and self-care tasks. This improvement is mainly attributed to the increased back bending capacity following surgery, which made these tasks less strenuous. Understanding these nuanced recovery patterns is key to developing personalised interventions for patients who derive less benefit in specific functional domains. For individuals whose daily activities or occupations involve substantial lifting, our data indicate the need to move beyond standard rehabilitation. A tailored pathway could incorporate pre-operative physical therapy focused on core and back strengthening, followed by a post-operative programme emphasising safe lifting techniques and gradual weight progression. Importantly, patients who fall outside the typical recovery curve, such as those with persistent deficits in lifting ability, may require more individualised strategies. By explicitly addressing this resistant functional domain, clinicians can better manage expectations and optimise long-term outcomes in this challenging subgroup.

Patients with greater disability was associated with higher odds of reported improvement, consistent with previous literature [12, 19-22]. This observation has two plausible explanations. First, these patients may notice more improvements because they have a higher potential for recovery. For example, a patient with severe mobility issues might regain the ability to walk, a significant gain compared to a patient with mild limitations who only improves slightly. Greater recovery potential leads to more noticeable gains in those with poorer baseline functionality. Second, patients with greater severity may have heightened awareness of their limitations, resulting in lower expectations for improvement. This may stem from their prolonged experience with the condition, where past treatments brought minimal change. Our findings highlight the importance of considering baseline disability in surgical decisions for lumbar surgery.

Our findings highlight an association between higher education and greater improvements in PROs, which aligns with previous research.[23, 24, 27] These studies show a positive link between higher education and enhanced PROs, patient satisfaction, physical function scores, and return-to-work rates after surgery. Higher education is associated with better health-seeking behaviours and adherence to rehabilitation programmes, crucial for recovery [50]. This may be because individuals with higher education tend to have better health literacy, allowing them to understand health conditions, surgical procedures, and post-surgical care more effectively. Additionally, better-educated patients may make more informed decisions and have realistic expectations, leading to more positive PROs [50, 51]. Conversely, patients with lower education levels may be less likely to experience improvement, potentially due to lower health literacy and limited understanding of post-operative care. This underscores the need for a more personalised, patient-centred education model, particularly for patients with less formal education. While some educational materials [52, 53] are provided to patients post-discharge, our findings suggest that a one-size-fits-all approach is insufficient. A multi-modal strategy could be implemented, combining simplified written materials, visual aids, and dedicated care navigators to reinforce instructions and serve as a consistent point of contact. Coupled with a structured follow-up plan featuring clear milestones and regular check-ins, this approach can help overcome barriers related to health literacy and improve adherence to rehabilitation protocols. Ultimately, such personalised patient support may foster more informed decision-making, set realistic expectations, and enhance long-term post-surgical outcomes in this vulnerable subgroup.

Regarding clinical factors, a diagnosis of prolapsed disc was associated with better surgical outcomes, especially for functional tasks like lifting and sitting, with benefits lasting up to 2 years. Consistent with previous research [12, 20] , isolated prolapsed discs are more easily diagnosed and can be treated with greater precision through surgery, such as discectomy, which minimises soft tissue damage and leads to better postoperative outcomes [54-56]. Conversely, other degenerative lumbar conditions may involve more complex pathology and uncertainty, complicating diagnosis and potentially affecting surgical precision. Our analysis also shows that outcomes vary between single levels (L4/5, L5/S1), double levels (L4 to S1), and combinations with other spinal levels, particularly in ADLs and social functioning. This variability may be due to differences in anatomical levels and biomechanics, as the affected tissues may vary across spinal levels. However, the underlying reasons remain unclear, highlighting the need for further research.

The improvements in ADLs, pain/discomfort, and social functioning seen at two years post-lumbar surgery among patients without comorbidities may be due to several factors. Initially, it may take time for these patients to fully benefit from rehabilitation, resulting in less noticeable improvements at one year. However, without comorbidities, they were more able to engage consistently in rehabilitation and healthy activities, leading to significant improvements in functionality and reduced disability by the second year [57]. Additionally, the absence of comorbidities allows for a more focused recovery process, which may take longer to show substantial benefits but ultimately results in better long-term outcomes [58]. Lastly, comorbidities often require medications or treatments that can hinder healing or post-surgical rehabilitation, so their absence may lead to clearer improvements over time.

Strengths and limitations

A major strength of this study is its ethnically diverse cohort and two-year follow-up, enhancing generalisability and providing a robust understanding of recovery across subgroups. To our knowledge, this is the first study to quantify effect sizes for improvements in each individual PRO dimension following lumbar spine surgery. Analysing outcomes at the dimension level reveals clinically relevant patterns of recovery and allows for more tailored, patient-centred interventions.

Our study has several limitations. Firstly, attrition was considerable, with 38% of patients lost at the 1-year follow-up and a further 23% by 2 years, raising concerns about non-response bias and reduced statistical power. Although baseline characteristics were similar between those retained and those lost to follow-up (Table S15), bias may still exist if patients who dropped out had systematically poorer outcomes. Reasons for attrition could include dissatisfaction, poor recovery, full recovery, or logistical barriers. To further mitigate this risk, we performed multiple imputation as a sensitivity check under the missing-at-random assumption. The consistency between imputed and complete-case results lends confidence to the robustness of our findings. Secondly, this retrospective cohort from a tertiary centre may over-represent patients with more complex conditions, introducing potential selection bias. This bias is difficult to avoid, particularly in the absence of a non-surgical comparator group to assess the relative effectiveness of surgery. Prospective studies including both surgical and non-surgical cohorts are needed to enable more balanced comparisons and strengthen causal inference. Thirdly, we excluded patients who reported no problems across all EQ-5D and ODI items at baseline, as ceiling effects would have limited the ability to detect change. Including them could have biased treatment effects towards the null. Their characteristics are detailed in Table S16. Fourth, the precision of some model estimates was limited, as indicated by wide confidence intervals. This likely reflects small sample sizes, low event frequencies, or potential model misspecification. Lastly, residual confounding from unmeasured surgical or social factors may have influenced the observed associations [59, 60]. In addition, interaction terms were not included in our models due to insufficient power to detect such effects reliably, as our primary focus was on identifying main effects associated with PRO improvement. To address these issues, future studies with larger samples should consider stratified analyses and more advanced modelling approaches to improve estimate precision and more thoroughly explore potential effect modifiers.

Conclusion

This longitudinal study shows significant improvements in all PROs from baseline to the 1-year follow-up, with a plateau at 2 years. Pain and social functioning domains showed large and sustained gains, while improvements in functional tasks such as lifting were negligible, despite subjective reports of improvement. It highlights the importance of pre-surgical assessments in predicting post-operative outcomes, particularly for patients with poorer baseline PROs and lower education levels. These findings suggest a need for tailored rehabilitation programmes that address specific functional limitations, such as lifting, and provide additional support for patients with lower education levels, who may benefit from simplified instructions, visual aids, and structured follow-up. Communication strategies should be adapted to enhance health literacy, and perioperative support could be expanded to include pre-operative coaching or care navigators for vulnerable subgroups. However, these results should be interpreted cautiously due to substantial attrition, which may have introduced non-response bias. Addressing attrition proactively in future studies could strengthen the reliability of these results and better inform pre-operative counselling, especially within Asian populations.

References

1. Ravindra, V. M., Senglaub, S. S., Rattani, A., Dewan, M. C., Härtl, R., Bisson, E., Park, K. B., & Shrime, M. G. (2018). Degenerative Lumbar Spine Disease: Estimating Global Incidence and Worldwide Volume. *Global Spine J*, 8(8), 784-794.
2. Kreiner, D. S., Hwang, S. W., Easa, J. E., Resnick, D. K., Baisden, J. L., Bess, S., Cho, C. H., DePalma, M. J., Dougherty, P., 2nd, Fernand, R., Ghiselli, G., Hanna, A. S., Lamer, T., Lisi, A. J., Mazanec, D. J., Meagher, R. J., Nucci, R. C., Patel, R. D., Sembrano, J. N., Sharma, A. K., Summers, J. T., Taleghani, C. K., Tontz, W. L., Jr., & Toton, J. F. (2014). An evidence-based clinical guideline for the diagnosis and treatment of lumbar disc herniation with radiculopathy. *Spine J*, 14(1), 180-191.
3. Kreiner, D. S., Shaffer, W. O., Baisden, J. L., Gilbert, T. J., Summers, J. T., Toton, J. F., Hwang, S. W., Mendel, R. C., & Reitman, C. A. (2013). An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spinal stenosis (update). *Spine J*, 13(7), 734-743.
4. Matz, P. G., Meagher, R. J., Lamer, T., Tontz, W. L., Jr., Annaswamy, T. M., Cassidy, R. C., Cho, C. H., Dougherty, P., Easa, J. E., Enix, D. E., Gunnoe, B. A., Jallo, J., Julien, T. D., Maserati, M. B., Nucci, R. C., O'Toole, J. E., Rosolowski, K., Sembrano, J. N., Villavicencio, A. T., & Witt, J. P. (2016). Guideline summary review: An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. *Spine J*, 16(3), 439-448.

5. Beighley, A., Zhang, A., Huang, B., Carr, C., Mathkour, M., Werner, C., Scullen, T., Kilgore, M. D., Maulucci, C. M., Dallapiazza, R. F., & Kalyvas, J. (2022). Patient-reported outcome measures in spine surgery: A systematic review. *J Craniovertebr Junction Spine*, 13(4), 378-389.

6. Makhni, E. C., & Hennekes, M. E. (2023). The Use of Patient-Reported Outcome Measures in Clinical Practice and Clinical Decision Making. *J Am Acad Orthop Surg*, 31(20), 1059-1066.

7. Briffa, N. (2018). The employment of Patient-Reported Outcome Measures to communicate the likely benefits of surgery. *Patient Relat Outcome Meas*, 9, 263-266.

8. Sajadi, K., Azarhomayoun, A., Jazayeri, S. B., Baigi, V., Ranjbar Hameghavandi, M. H., Rostamkhani, S., Atlasi, R., Faghih Jooybari, M., Ghodsi, Z., Vaccaro, A. R., Khorasanizadeh, M., & Rahimi-Movaghar, V. (2022). Long-Term Outcomes of Laminectomy in Lumbar Spinal Stenosis: A Systematic Review and Meta-Analysis. *Asian J Neurosurg*, 17(2), 141-155.

9. Oster, B. A., Kikanloo, S. R., Levine, N. L., Lian, J., & Cho, W. (2020). Systematic Review of Outcomes Following 10-Year Mark of Spine Patient Outcomes Research Trial for Intervertebral Disc Herniation. *Spine (Philadelphia, Pa. 1976)*, 45(12), 825-831.

10. Ailon, T., Tee, J., Manson, N., Hall, H., Thomas, K., Rampersaud, Y. R., Yee, A., Dea, N., Glennie, A., Bailey, C., Christie, S., Weber, M. H., Nataraj, A., Paquet, J., Johnson, M., Norton, J., Ahn, H., McIntosh, G., & Fisher, C. G. (2019). Patient-reported outcomes following surgery for degenerative spondylolitshtesis: comparison of a universal and multitier health care system. *Spine J*, 19(1), 24-33.

11. Ayling, O. G. S., Ailon, T., Craig, M., Dea, N., McIntosh, G., Abraham, E., Jacobs, W. B., Johnson, M. G., Paquet, J., Yee, A., Hall, H., Bailey, C., Manson, N., Rampersaud, Y. R., Thomas, K., & Fisher, C. G. (2023). Patient-Reported Outcomes Following Surgery for Lumbar Disc Herniation: Comparison of a Universal and Multitier Health Care System. *Global Spine J*, 13(7), 1695-1702.

12. Khor, S., Lavallee, D., Cizik, A. M., Bellabarba, C., Chapman, J. R., Howe, C. R., Lu, D., Mohit, A. A., Oskouian, R. J., Roh, J. R., Shonnard, N., Dagal, A., & Flum, D. R. (2018). Development and Validation of a Prediction Model for Pain and Functional Outcomes After Lumbar Spine Surgery. *JAMA Surg*, 153(7), 634-642.

13. Calek, A. K., Hochreiter, B., & Buckland, A. J. (2024). Reassessing the minimum two-year follow-up standard after lumbar decompression surgery: a 2-months follow-up seems to be an acceptable minimum. *Spine J*.

14. Lurie, J. D., Tosteson, T. D., Tosteson, A., Abdu, W. A., Zhao, W., Morgan, T. S., & Weinstein, J. N. (2015). Long-term outcomes of lumbar spinal stenosis: eight-year results of the Spine Patient Outcomes Research Trial (SPORT). *Spine (Philadelphia, Pa. 1976)*, 40(2), 63-76.

15. Weinstein, J. N., Tosteson, T. D., Lurie, J. D., Tosteson, A. N., Hanscom, B., Skinner, J. S., Abdu, W. A., Hilibrand, A. S., Boden, S. D., & Deyo, R. A. (2006). Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT): a randomized trial. *JAMA*, 296(20), 2441-2450.

16. Weinstein, J. N., Lurie, J. D., Tosteson, T. D., Hanscom, B., Tosteson, A. N., Blood, E. A., Birkmeyer, N. J., Hilibrand, A. S., Herkowitz, H., Cammisa, F. P., Albert, T. J., Emery, S. E., Lenke, L. G., Abdu, W. A., Longley, M., Errico, T. J., & Hu, S. S. (2007). Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. *N Engl J Med*, 356(22), 2257-2270.

17. Weinstein, J. N., Lurie, J. D., Tosteson, T. D., Tosteson, A. N. A., Blood, E. A., Abdu, W. A., Herkowitz, H., Hilibrand, A., Albert, T., & Fischgrund, J. (2008). Surgical Versus Nonoperative Treatment for Lumbar Disc Herniation : Four-Year Results for the Spine Patient Outcomes Research Trial (SPORT). *Spine (Philadelphia, Pa. 1976)*, 33(25), 2789-2800.

18. Kagaya, H., Takahashi, H., Sugawara, K., Kuroda, T., & Takahama, M. (2005). Quality of life assessment before and after lumbar disc surgery. *J Orthop Sci*, 10(5), 486-489.

19. Achttien, R. J., Powell, A., Zoulas, K., Staal, J. B., & Rushton, A. (2022). Prognostic factors for outcome following lumbar spine fusion surgery: a systematic review and narrative synthesis. *Eur Spine J*, 31(3), 623-668.

20. Lubelski, D., Feghali, J., Nowacki, A. S., Alentado, V. J., Planchard, R., Abdullah, K. G., Sciubba, D. M., Steinmetz, M. P., Benzel, E. C., & Mroz, T. E. (2021). Patient-specific prediction model for clinical and quality-of-life outcomes after lumbar spine surgery. *J Neurosurg Spine*, 34(4), 580-588.

21. Hébert, J. J., Abraham, E., Wedderkopp, N., Bigney, E., Richardson, E., Darling, M., Hall, H., Fisher, C. G., Rampersaud, Y. R., Thomas, K. C., Jacobs, W. B., Johnson, M., Paquet, J., Attabib, N., Jarzem, P., Wai, E. K., Rasoulinejad, P., Ahn, H., Nataraj, A., Stratton, A., & Manson, N. (2020). Preoperative Factors Predict Postoperative Trajectories of Pain and Disability Following Surgery for Degenerative Lumbar Spinal Stenosis. *Spine (Philadelphia, Pa. 1976)*, 45(21), E1421-e1430.

22. Hey, H. W. D., Luo, N., Chin, S. Y., Lau, E. T. C., Wang, P., Kumar, N., Lau, L.-L., Ruiz, J. N., Thambiah, J. S., Liu, K.-P. G., & Wong, H.-K. (2018). The Predictive Value of Preoperative Health-Related Quality-of-Life Scores on Postoperative Patient-Reported Outcome Scores in Lumbar Spine Surgery. *Global Spine J*, 8(2), 156-163.

23. Alnaami, I., Shakir, S., Almalwi, K., Alquzi, A., Asiri, M., Asiri, M., Alqahtani, N., & Shehata, S. (2020). Quality of life in post lumbar microdiscectomy patients using the EuroQol 5-dimension 5-level scale. *Saudi Surg J*, 8(1), 21-26.

24. Chouhdari, A., Rezaei, O., Rezapour, P., Samadian, M., Shahrabi Farahani, H., Hajiesmaeili, M., & Ebrahimzadeh, K. (2019). Effect of Basic Characteristics on Improving Quality of Life After Lumbar Spine Decompression Surgery. 6(3), e90159.
25. Olson, P. R., Lurie, J. D., Frymoyer, J., Walsh, T., Zhao, W., Morgan, T. S., Abdu, W. A., & Weinstein, J. N. (2011). Lumbar Disc Herniation in the Spine Patient Outcomes Research Trial: Does Educational Attainment Impact Outcome? *Spine (Philadelphia, Pa. 1976)*, 36(26), 2324-2332.
26. Ibrahim, J. M., Singh, P., Beckerman, D., Hu, S. S., Tay, B., Deviren, V., Burch, S., & Berven, S. H. (2019). Outcomes and Quality of Life Improvement After Multilevel Spinal Fusion in Elderly Patients. *Global Spine J*, 10(2), 153-159.
27. McGuire, K. J., Khaleel, M. A., Rihn, J. A., Lurie, J. D., Zhao, W., & Weinstein, J. N. (2014). The Effect of Extreme Obesity on Outcomes of Treatment for Lumbar Spinal Conditions: Subgroup Analysis of the Spine Patient Outcomes Research Trial (SPORT). *Spine (Philadelphia, Pa. 1976)*, 39(23), 1975-1980.
28. Alentado, V. J., Caldwell, S., Gould, H. P., Steinmetz, M. P., Benzel, E. C., & Mroz, T. E. (2017). Independent predictors of a clinically significant improvement after lumbar fusion surgery. *Spine J*, 17(2), 236-243.
29. Stienen, M. N., Joswig, H., Smoll, N. R., Corniola, M. V., Schaller, K., Hildebrandt, G., & Gautschi, O. P. (2016). Short- and Long-Term Outcome of Microscopic Lumbar Spine Surgery in Patients with Predominant Back or Predominant Leg Pain. *World Neurosurg*, 93, 458-465.e451.
30. Park, D. K., An, H. S., Lurie, J. D., Zhao, W., Tosteson, A., Tosteson, T. D., Herkowitz, H., Errico, T., & Weinstein, J. N. (2010). Does Multilevel Lumbar Stenosis Lead to Poorer Outcomes?: A Subanalysis of the Spine Patient Outcomes Research Trial (SPORT) Lumbar Stenosis Study. *Spine (Philadelphia, Pa. 1976)*, 35(4), 439-446.
31. Benchimol, E. I., Smeeth, L., Guttmann, A., Harron, K., Moher, D., Petersen, I., Sørensen, H. T., von Elm, E., & Langan, S. M. (2015). The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. *PLoS Med*, 12(10), e1001885.
32. von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Bmj*, 335(7624), 806-808.
33. Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., & Conde, J. G. (2009). Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics*, 42(2), 377-381.

34. Harris, P. A., Taylor, R., Minor, B. L., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G., Delacqua, F., Kirby, J., & Duda, S. N. (2019). The REDCap consortium: Building an international community of software platform partners. *Journal of Biomedical Informatics*, 95, 103208.
35. EuroQol Research Foundation. (2018). *EQ-5D-3L User Guide*. from https://euroqol.org/publications/user-guides/
36. Luo, N., Wang, P., Thumboo, J., Lim, Y.-W., & Vrijhoef, H. J. M. (2014). Valuation of EQ-5D-3L Health States in Singapore: Modeling of Time Trade-Off Values for 80 Empirically Observed Health States. *PharmacoEconomics*, 32(5), 495-507.
37. Qian, X., Tan, R. L.-Y., Chuang, L.-H., & Luo, N. (2020). Measurement Properties of Commonly Used Generic Preference-Based Measures in East and South-East Asia: A Systematic Review. *PharmacoEconomics*, 38(2), 159-170.
38. Finch, A. P., Dritsaki, M., & Jommi, C. (2016). Generic Preference-based Measures for Low Back Pain: Which of Them Should Be Used? *Spine (Philadelphia, Pa. 1976)*, 41(6), E364-374.
39. Yates, M., & Shastri-Hurst, N. (2017). The Oswestry Disability Index. *Occup Med*, 67(3), 241-242.
40. Selva-Sevilla, C., Ferrara, P., & Gerónimo-Pardo, M. (2019). Psychometric Properties Study of the Oswestry Disability Index in a Spanish Population With Previous Lumbar Disc Surgery: Homogeneity and Validity. *Spine (Philadelphia, Pa. 1976)*, 44(7).
41. Kane, M., & Esther, S. Y. (2024). Using Cliff's Delta as a Non-Parametric Effect Size Measure: An Accessible Web App and R Tutorial. *Practical Assessment, Research, and Evaluation*, 29(1).
42. Tai, B. C., & Machin, D. (2013). Logistic Regression. In B.C. Tai. & D. Machin. (Eds.), Regression Methods for Medical Research (pp. 64-97).
43. Azur, M. J., Stuart, E. A., Frangakis, C., & Leaf, P. J. (2011). Multiple imputation by chained equations: what is it and how does it work? *Int J Methods Psychiatr Res*, 20(1), 40-49.
44. Hareni, N., Ebrahimnia, S., Rosengren, B. E., & Karlsson, M. K. (2024). Recovery pattern after decompression of central lumbar spinal stenosis: a prospective observational cohort study. *J Orthop Surg Res*, 19(1), 200.
45. Rushton, A., Jadhakhan, F., Masson, A., Athey, V., Staal, J. B., Verra, M. L., Emms, A., Reddington, M., Cole, A., Willems, P. C., Benneker, L., Heneghan, N. R., & Soundy, A. (2020). Patient journey following lumbar spinal fusion surgery (FuJourn): A multicentre exploration of the immediate post-operative period using qualitative patient diaries. *PLOS ONE*, 15(12), e0241931.

46. Ashton-James, C. E., Anderson, S. R., Mackey, S. C., & Darnall, B. D. (2022). Beyond pain, distress, and disability: the importance of social outcomes in pain management research and practice. *Pain*, 163(3), e426-e431.

47. Greenwood, J., Hurley, M., McGregor, A., McCourt, O., & Jones, F. (2022). A qualitative evaluation of participants experiences of living with back pain, lumbar fusion surgery, and post-operative rehabilitation. *Pilot Feasibility Stud*, 8(1), 91.

48. Coronado, R. A., Robinette, P. E., Henry, A. L., Pennings, J. S., Haug, C. M., Skolasky, R. L., Riley, L. H., Neuman, B. J., Cheng, J. S., Aaronson, O. S., Devin, C. J., Wegener, S. T., & Archer, K. R. (2021). Bouncing back after lumbar spine surgery: early postoperative resilience is associated with 12-month physical function, pain interference, social participation, and disability. *Spine J*, 21(1), 55-63.

49. Özden, F., & Koçyiğit, G. Z. (2024). The effect of early rehabilitation after lumbar spine surgery: a systematic review and meta-analysis. *Egypt J Neurosurg*, 39(1), 8.

50. Manni, T., Ferri, N., Vanti, C., Ferrari, S., Cuoghi, I., Gaeta, C., Sgaravatti, I., & Pillastrini, P. (2023). Rehabilitation after lumbar spine surgery in adults: a systematic review with meta-analysis. *Arch Physiother*, 13(1), 21.

51. Lans, A., Bales, J. R., Fourman, M. S., Borkhetaria, P. P., Verlaan, J.-J., & Schwab, J. H. (2023). Health Literacy in Orthopedic Surgery: A Systematic Review. *HSS Journal®*, 19(1), 120-127.

52. National University Health System. (2023). *How to Take Care of Your Back [Patient Education Brochure].* from https://www.nuh.com.sg/docs/nuhlibraries/brochures-document/how-to-take-care-of-your-back.pdf?sfvrsn=74cc8499_1

53. National University Health System. (2020). *Spinal Rehabilitation: Main Conditions [Patient Information Leaflet]*. from https://www.nuh.com.sg/docs/nuhlibraries/content-document/care-at-nuh/specialties/rehabilitation/our-services/main-conditions---spinal-rehabilitation.pdf

54. Kim, H. S., Wu, P. H., & Jang, I. T. (2020). Lumbar Degenerative Disease Part 1: Anatomy and Pathophysiology of Intervertebral Discogenic Pain and Radiofrequency Ablation of Basivertebral and Sinuvertebral Nerve Treatment for Chronic Discogenic Back Pain: A Prospective Case Series and Review of Literature. *Int J Mol Sci*, 21(4).

55. Romaniyanto, Mahyudin, F., Sigit Prakoeswa, C. R., Notobroto, H. B., Tinduh, D., Ausrin, R., Rantam, F. A., Suroto, H., Utomo, D. N., & Rhatomy, S. (2022). An update of current therapeutic approach for Intervertebral Disc Degeneration: A review article. *Ann Med Surg (Lond)*, 77, 103619.

56. Wu, P. H., Kim, H. S., & Jang, I. T. (2020). Intervertebral Disc Diseases PART 2: A Review of the Current Diagnostic and Treatment Strategies for Intervertebral Disc Disease. *Int J Mol Sci*, 21(6).

57. Yang, H. L., Mo, B. R., Molassiotis, A., Wang, M., He, G. L., & Xie, Y. J. (2022). Relationship between multimorbidity and composite lifestyle status in Shenzhen, China. *J Multimorb Comorb*, 12, 26335565221123990.

58. Bays, A., Stieger, A., Held, U., Hofer, L. J., Rasmussen-Barr, E., Brunner, F., Steurer, J., & Wertli, M. M. (2021). The influence of comorbidities on the treatment outcome in symptomatic lumbar spinal stenosis: A systematic review and meta-analysis. *N Am Spine Soc J*, 6, 100072.

59. Lin, M.-L., Pang, M.-C. S., & Chen, C.-H. (2013). Family as a whole: elective surgery patients' perception of the meaning of family involvement in decision making. *J Clin Nurs*, 22(1-2), 271-278.

60. Lin, J. L., Lipstein, E. A., Wittenberg, E., Tay, D., Lundstrom, R., Lundstrom, G. L., Sediqzadah, S., & Wright, D. R. (2021). Intergenerational Decision Making: The Role of Family Relationships in Medical Decision Making. *MDM Policy Pract*, 6(2), 23814683211039468.

Figure Legends

Fig. 1. STROBE diagram outlining the flow of patients within the study. T_0 = Baseline, T_1 = 1-year follow-up, and T_2 = 2-year follow-up.

Fig. 2. 1- and 2-Year PROs for lumbar spine surgery in patients with degenerative lumbar conditions.

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Table I Socio-demographics, clinical data, and PROs for entire cohort

Variables	Baseline (N= 1,195)		1st Year Follow-up (N=741)		2nd Year Follow-up (Baseline (N=440)	
	Mean (SD)	Median [Range]	Mean (SD)	Median [Range]	Mean (SD)	Median [Range]
Age, n (%)	58.1 (16.1)	61 [19-84]	57.9 (15.9)	61 [19-84]	57.9 (16.0)	61 [18-84]
Younger adults (<65)	688 (57.6)		440 (59.4)		260 (59.1)	
Older adults (≥65)	507 (42.4)		301 (40.6)		180 (40.9)	
Gender, n (%)						
Female	579 (48.5)		363 (49.0)		235 (53.4)	
Male	616 (51.5)		378 (51.0)		205 (46.6)	
Ethnicity, n (%)						
Chinese	840 (70.3)		531 (71.7)		321 (73.0)	
Malay	145 (12.1)		94 (12.7)		62 (14.1)	
Indian	103 (8.6)		63 (8.5)		32 (7.2)	
Others	107 (9.0)		53 (7.2)		25 (5.7)	
BMI, n (%)	26.3 (4.7)	25.6 [17.8-41.0]	26.2 (4.6)	25.6 [18.0-41.0]	26.3 (4.6)	25.6 [18.4-41.0]
Overweight/Obese (≥25)	674 (56.4)		410 (55.3)		244 (55.5)	
Normal/Underweight (<25)	521 (43.6)		331 (44.7)		196 (44.5)	
Level of education, n (%)						
Primary	237 (19.9)		149 (20.1)		83 (18.9)	
Secondary	376 (31.5)		245 (33.1)		148 (33.6)	
College/Diploma	308 (25.8)		188 (25.4)		122 (27.7)	
University & above	273 (22.9)		159 (21.5)		87 (19.8)	
Comorbidities, n (%)						
Absence	662 (55.4)		418 (56.4)		246 (55.9)	
Presence	533 (44.6)		323 (43.6)		194 (44.1)	
Diagnosis, n (%)						
Stenosis	484 (40.5)		287 (38.7)		175 (39.8)	
Prolapsed Disc	273 (22.9)		166 (22.4)		84 (19.1)	
Spondylolisthesis	236 (19.8)		136 (18.4)		72 (16.4)	
Degenerative Disc Disease	202 (16.9)		152 (20.5)		109 (24.8)	
Level of spine, n (%)						
Lumbar						
- L4/5	437 (36.6)		286 (38.6)		166 (37.7)	
- L4/S1	128 (10.7)		85 (11.5)		50 (11.4)	
- L5/S1	202 (16.9)		122 (16.5)		69 (15.7)	
- Others	345 (28.9)		202 (27.3)		122 (27.7)	
Mixed level	82 (6.9)		46 (6.2)		33 (7.5)	
Pain score (0-100)	56.0 (29.5)	60 [0-100]	18.6 (24.8)	0 [0-85]	17.1 (23.8)	0 [0-80]
EQ-5D Index (-0.769-1)	0.48 (0.34)	0.62 [-0.48-1.00]	0.81 (0.25)	0.81 [-0.17-1.00]	0.80 (0.23)	0.80 [-0.10-1.00]
EQ VAS (0-100)	65.5 (16.3)	70 [20-95]	72.9 (13.3)	75 [30-100]	71.2 (14.5)	70 [30-100]

Variables	Baseline (N= 1,195)		1st Year Follow-up (N=741)		2nd Year Follow-up (Baseline (N=440)	
	Mean (SD)	Median [Range]	Mean (SD)	Median [Range]	Mean (SD)	Median [Range]
ODI (0-100%)	42.0 (20.5)	42 [0-88]	18.9 (19.4)	12 [0-76]	18.5 (18.1)	12 [0-70]

Table II Improvements in PROs among individuals with pre-operative health problems at different time points

PRO cluster	Baseline to 1st Year Follow-up				Baseline to 2nd Year Follow-up			
	N [a]	% of improved individuals	δ (95% CI)	Interpretation	N [a]	% of improved individuals	δ (95% CI)	Interpretation
Activities of Daily Living (ADLs)								
Mobility (EQ-5D item 1)	573	65.6	0.42 (0.38, 0.46)	Moderate	352	61.9	0.39 (0.34, 0.44)	Moderate
Walking (ODI item 4)	593	75.2	0.45 (0.41, 0.50)	Moderate	359	78.3	0.43 (0.37, 0.48)	Moderate
Self-care (EQ-5D item 2)	308	81.8	0.26 (0.22, 0.29)	Small	200	82.0	0.27 (0.23, 0.31)	Small
Personal care (ODI item 2)	342	84.5	0.33 (0.29, 0.36)	Moderate	195	86.7	0.34 (0.29, 0.38)	Moderate
Functional tasks								
Lifting (ODI item 3)	670	46.9	0.04 (-0.01, 0.09)	Negligible	392	56.4	0.04 (-0.03, 0.10)	Negligible
Sleeping (ODI item 7)	368	82.6	0.32 (0.27, 0.36)	Small	217	81.6	0.31 (0.26, 0.35)	Small
Sitting (ODI item 5)	438	81.5	0.34 (0.29, 0.38)	Moderate	255	82.4	0.34 (0.29, 0.39)	Moderate
Standing (ODI item 6)	643	80.1	0.52 (0.48, 0.57)	Large	388	80.4	0.52 (0.47, 0.57)	Small
Mental health								
Anxiety/ depression (EQ-5D item 5)	397	78.3	0.34 (0.30, 0.38)	Moderate	224	67.9	0.27 (0.22, 0.32)	Small
Pain and discomfort								
Pain/discomfort (EQ-5D item 4)	690	63.8	0.55 (0.51, 0.58)	Large	410	60.2	0.53 (0.48, 0.57)	Large
Pain intensity (ODI item 1)	590	83.7	0.56 (0.52, 0.60)	Large	349	84.2	0.59 (0.55, 0.64)	Large
Social functioning								
Usual activities (EQ-5D item 3)	635	63.2	0.46 (0.42, 0.50)	Large	376	63.0	0.47 (0.42, 0.52)	Large
Social life (ODI item 9)	624	73.6	0.48 (0.43, 0.52)	Large	366	74.3	0.49 (0.43, 0.54)	Large
Travelling (ODI item 10)	630	81.1	0.53 (0.49, 0.58)	Large	310	84.0	0.54 (0.49, 0.59)	Large
Sex life (ODI item 8)	544	82.0	0.48 (0.44, 0.52)	Large	330	85.2	0.50 (0.45, 0.54)	Large

[a] Individuals with pre-operative health problems; δ: Cliff's delta; CI: Confidence interval.

Table III Odds ratios of improvement for each factor across different PROs and follow-up periods

Odds of improvement in each PROs	ADLs				Functional tasks				Mental	Pain/discomfort		Social functioning			
	MO	Walking	SC	Personal care	Lifting	Sleeping	Sitting	Standing	AD	PD	Pain	UA	Social life	Travelling	Sex life
Follow-up at 1st Year															
Baseline PROs (Ref: Level 2)															
Severe (Level 3)	9.30	1.80			4.84	2.12	3.56	3.22		21.5	4.82	19.1	6.18	3.00	2.45
Gender (Ref: Female)															
Male															
Age (Ref: Older adults)															
Younger adults	1.87	3.15			1.52		0.50						1.58		
Ethnicity (Ref: Non-Chinese)															
Chinese	2.13	1.73										1.59			
BMI (Ref: Overweight/Obese)															
Normal/Underweight											1.91				
Level of education (Ref: Primary & Secondary)															
Tertiary	2.63	3.67	2.52	2.35	1.68		2.34	2.53	1.94	2.59	2.23	2.57	2.61	3.52	
Comorbidities (Ref: Presence)															
Absence	1.57											1.66			
Diagnosis (Ref: Stenosis)															
Prolapsed Disc	1.79				2.14	2.86	3.12	2.01					1.04	1.77	
Spondylolisthesis	1.12				1.07	1.09	0.95	1.24					0.60	0.95	
Degenerative Disc Disease	1.02				1.38	2.38	1.84	0.80					1.23	0.93	
Level of spine (Ref: Lumbar - L4/5)															
Lumbar - L4/S1	0.86		2.22	6.13				0.89			2.04	0.50	1.06		1.35
Lumbar – L5/S1	0.93		0.71	0.62				1.11			0.87	0.54	0.58		0.90
Lumbar – Others	0.76		0.50	0.57				0.59			1.94	0.40	0.63		0.54
Mixed level	0.32		0.28	0.65				0.45			0.72	0.30	0.37		0.34
Follow-up at 2nd Year															
Baseline PROs (Ref: Level 2)															
Severe (Level 3)	18.1				5.54	4.08	2.01	2.05		23.7	3.08	7.20	6.59	3.01	2.84
Gender (Ref: Female)															
Male								2.06							
Age (Ref: Older adults)															
Younger adults	2.59	2.21			2.10							1.99			
Ethnicity (Ref: Non-Chinese)															
Chinese													1.94		

Odds of improvement in each PROs	ADLs				Functional tasks				Mental	Pain/discomfort		Social functioning			
	MO	Walking	SC	Personal care	Lifting	Sleeping	Sitting	Standing	AD	PD	Pain	UA	Social life	Travelling	Sex life
BMI (Ref: Overweight/Obese)															
Normal/Underweight															
Level of education (Ref: Primary & Secondary)															
Tertiary													1.84		
Comorbidities (Ref: Presence)															
Absence	2.62		3.21							2.20		1.96	3.01	3.96	
Diagnosis (Ref: Stenosis)															
Prolapsed Disc		1.88			3.41		3.31		1.60						
Spondylolisthesis		2.46			1.14		1.01		3.09						
Degenerative Disc Disease		1.07			1.34		1.82		1.49						
Level of spine (Ref: Lumbar - L4/5)															
Lumbar - L4/S1								1.72		0.98					
Lumbar – L5/S1								1.51		0.68					
Lumbar – Others								0.55		0.51					
Mixed level								0.91		0.79					

Tertiary: College, Diploma & University; ADLs: Activities of daily living; MO: Mobility; SC: Self-care; UA: Usual activities; PD: Pain/discomfort; AD: Anxiety/depression; Pain: Pain intensity; Mental: Mental Health; Ref: Reference group; Numbers: Odds Ratio (E.g., Those with severe problem is 1.85 times more likely to improve in walking that those with some problem at baseline); Light grey coloured cell: Non-significant; Dark grey coloured cell: Statistically significant.

Figure 1

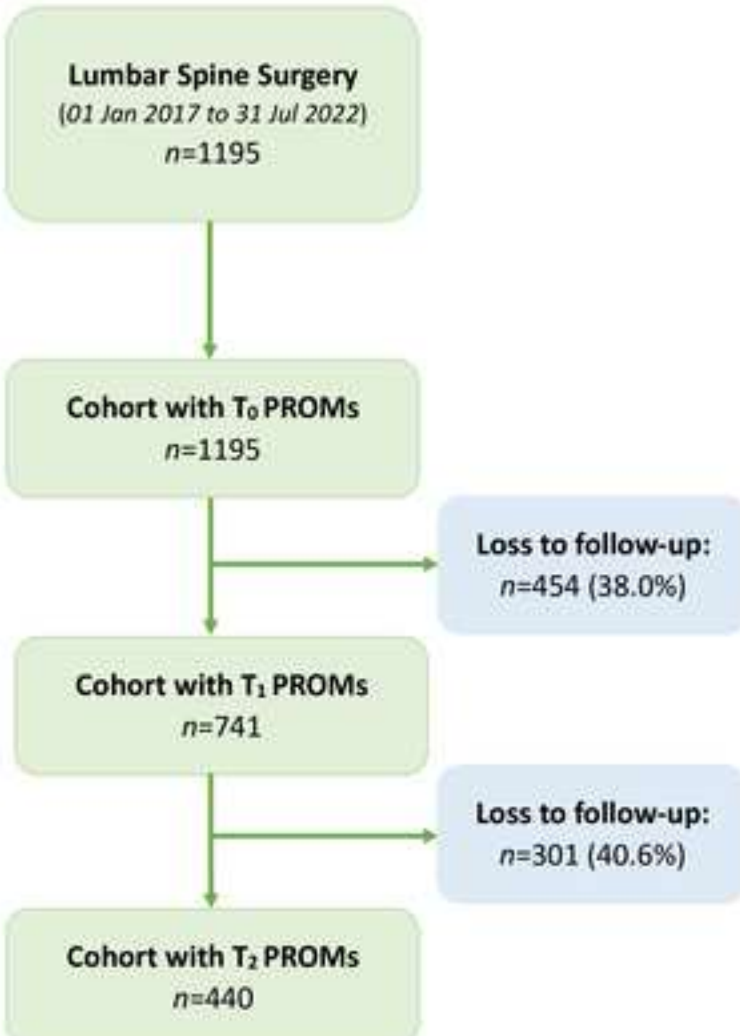
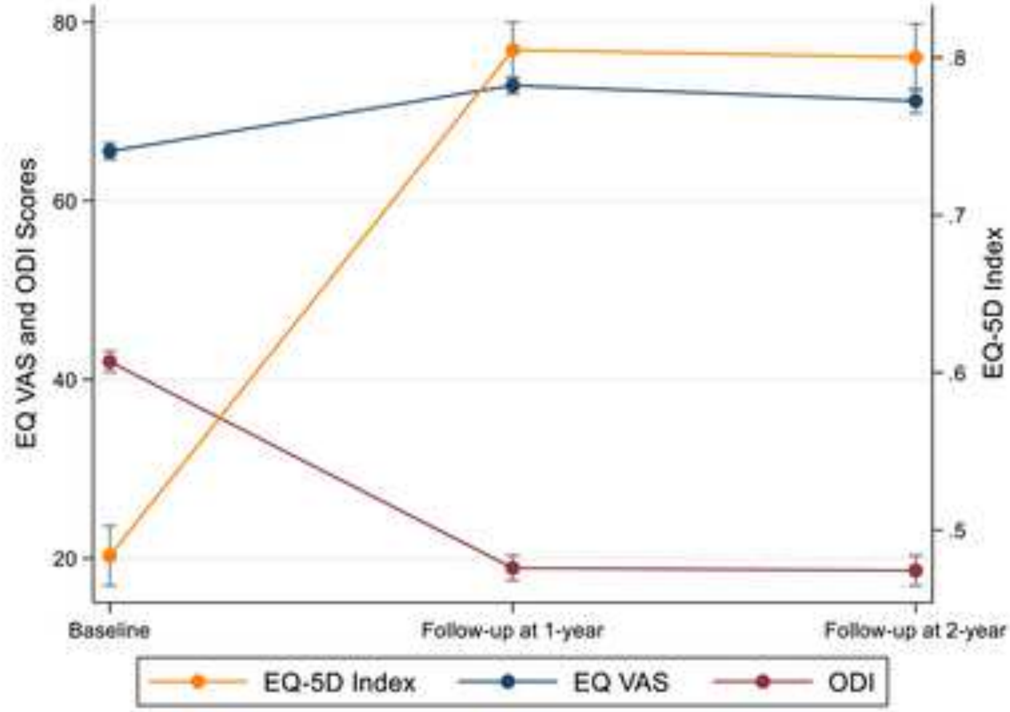

Lumbar Spine Surgery
(01 Jan 2017 to 31 Jul 2022)
n=1195
Cohort with T0 PROMs
n=1195
Loss to follow-up:
n=454 (38.0%)
Cohort with T1 PROMs
n=741
Loss to follow-up:
n=301 (40.6%)
Cohort with T2 PROMs
n=440

Figure 2


80
60
40
20
EQ VAS and ODI Scores
.8
.7
.6
.5
EQ-5D Index
Baseline
Follow-up at 1-year
Follow-up at 2-year
EQ-5D Index
EQ VAS
ODI

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Electronic supplementary material
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Plain English summary

This study investigated the outcomes of lumbar spine surgery in 1,195 patients in Singapore. Significant improvements in patient-reported outcomes (PROs), such as pain reduction and improved social function, were observed within the first year after surgery, with limited further improvement in the second year. Higher education and conditions affecting only the L4/5 spinal level were associated to better outcomes in activities of daily living, pain/discomfort, and social functioning. Higher education and prolapsed disc diagnosis were associated with functional task improvements. At 2 years, poorer baseline PROs remained influential, while the absence of comorbidities emerged as a significant factor. These findings emphasize the importance of pre-operative assessments and patient education to optimize surgical outcomes.