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Patient Recovery Following Uniportal Endoscopic Vs Open Lumbar Spine Surgery: Objective Analysis of Postoperative Mobility and Gait Patterns Using Wearable Sensors

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ABSTRACT

Background: There has been a gradual shift from open spine surgery to minimally invasive techniques such as endoscopic spine surgery to reduce approach-related trauma, collateral damage, and complications. While recovery following surgery has been measured using subjective measures including patient-reported outcome measures, the introduction of smart wearable devices now provides both an objective and continuous method of patient assessment. This prospective study compares patient recovery after uniportal endoscopic and open lumbar spine surgery by analyzing mobility and gait metrics captured by a wearable sensor.

Methods: Participants included 24 patients who underwent a single-level uniportal endoscopic lumbar decompression or open posterior lumbar fusion. During the first 48 hours after surgery, patients wore a sensor that continuously monitored position, step count, and gait metrics.

Results: In the immediate postoperative period, endoscopic spine surgery patients experienced a quicker return to mobility, with less time lying down, higher step count, faster gait velocity, lower double support percentage, and reduced variability, compared with open spine surgery patients.

Conclusion: There are key differences in patient mobility and gait following uniportal endoscopic and open spine surgery. Endoscopic spine surgery patients had faster recovery, which can guide resource allocation toward the development of training programs and support the advancement of spine endoscopy to address a broader range of pathologies. This pilot study highlights the potential for wearable devices to be used in further studies to form spine surgery recovery trajectories, allowing targeted rehabilitation and prompt intervention for deviations in patient recovery.

Clinical Relevance: This study demonstrates the benefits of endoscopic spine surgery for improved postoperative recovery in terms of mobility and gait metrics. Additionally, it highlights the potential for wearable sensor technology to provide an objective and continuous method for assessing postoperative outcomes and for the development of individualized rehabilitation protocols. These findings support the broader adoption of endoscopic techniques and emphasize the value of incorporating wearable devices into postoperative monitoring to optimize patient care.

Level of Evidence: 3.

Endoscopic Minimally Invasive Surgery

Keywords: neuroendoscopy, spinal disease, wearable electronic devices, gait analysis

INTRODUCTION

Degenerative lumbar spine disease causes significant disability worldwide. The annual incidence of symptomatic degenerative spine disease is estimated to be about 266 million people globally, with an annual healthcare cost of $40 billion in the United States alone.[1,2] Two major lumbar pathologies are spinal stenosis and spondylolisthesis. Surgical interventions are indicated when these pathologies impact patients' quality of life and conservative measures do not provide sufficient relief from symptoms.

Transition From Open to Endoscopic Spine Surgery

Traditional open lumbar spine surgery has a traumatic approach that involves extensive tissue dissection and iatrogenic damage, resulting in significant postoperative pain and risk of complications.[3] Consequently, there has been an ongoing shift from open spine surgery to minimally invasive techniques, including endoscopic spine surgery, to reduce tissue trauma and collateral damage, similar to the transformative impact of laparoscopy in general surgery.[4–6] While surgeons have demonstrated interest in endoscopic spine surgery to improve recovery and surgical morbidity, broader practice is limited by the steep learning curve, lack of objective evidence in the literature, and time taken to learn endoscopic skills, as surgeons need to perform at least 20 cases to become familiar with the technique.[7,8]

Specialized surgical equipment and the introduction of 3D endoscopy have decreased the learning curve and allowed surgeons to target a broader range of pathologies. However, there are still challenges to lumbar spine endoscopy due to limited space, lesions being distant from the skin, extensive bone work, and close proximity of neural structures.[9,10] Thus, widespread implementation is restricted by the need for surgeons to gain further skills and the lack of formalized spine endoscopy training.[7] The potential for endoscopic spine surgery to enhance patient recovery outcomes highlights the need for research that analyzes the differences in postoperative outcomes of endoscopic and open lumbar spine surgery.

Measures of Recovery Following Spine Surgery

The current gold standard measure of recovery is patient-reported outcome measures (PROMs), including the EuroQol- 5 Dimension (EQ-5D) Questionnaire, Oswestry Disability Index (ODI), and visual analog scale (VAS), which provide patients' perception of their health and quality of life.[11–13] However, there are innate biases with self-reported measures because they are highly personal and can be influenced by factors including mood, culture, and pain tolerance. Consequently, while PROMs provide valuable insight into how a single patient perceives their recovery, the subjective bias limits reliability when comparing outcomes across different patients and surgical interventions.[14]

The introduction of smart wearable devices has provided a more objective method of patient assessment. While PROMs have sampling bias as they only provide insight into the patients' perspective at a single time point and lack the capacity for continuous assessment, wearable devices can provide continuous data on patient progress, so healthcare practitioners can detect trends that might be overlooked by PROMs.[15,16] Analysis of patients' mobility and gait using wearable sensors can provide objective evidence of recovery after lumbar surgery while eliminating subjective bias. Continuous data from wearable devices may also allow for early recognition of deterioration and efficient delivery of care as health care practitioners can intervene promptly when unexpected changes are detected, rather than waiting for patient-reported feedback.

Comparing the Recovery of Endoscopic and Open Spine Surgery

Existing literature has only compared the recovery outcomes of open and endoscopic lumbar spine surgery patients using subjective measures such as PROMs at single time points.[4,17–19] Gibson et al[20] reported similar VAS and ODI scores for endoscopic and open-surgery patients at 3 months (VAS: 3.0 vs 3.1; n = 140; P = 0.66, ODI: 27 vs 27; n = 140; P = 0.84). However, Chen et al[17] reported that immediate postoperative VAS scores improved for endoscopic spine surgery patients but worsened for open spine surgery patients (3.5 vs −0.56; n = 43; $P < 0.0001$). The inconsistent findings can be attributed to varied time points at which these measures were obtained and the highly personal nature of PROMs, which may skew outcome measurements and limit comparability between patients.[14,21] Consequently, objective measures are required to more accurately compare patient recovery following different interventions.

Improvements in gait and mobility are critical to postoperative recovery as they are directly correlated with better functional outcomes and quality of life, with patients who walk more in the first postoperative week being more likely to have improved function on ODI questionnaires at 6 months (OR: 1.18; 95% CI: 1.01–1.37).[22] Consequently, it is useful to compare the postoperative mobility and gait patterns of patients following endoscopic and open lumbar spine surgery to determine the differences in recovery. As with all upcoming techniques, analysis of advantages and limitations is essential to inform decisions on resource allocation toward training, implementation, and advancement of techniques that optimize patient outcomes. Data on patient recovery following spine surgery interventions can also contribute to the development of recovery trajectories, for targeted rehabilitation and prompt intervention when there are deviations from expected recovery.

The present study aims to compare patient recovery after either single-level uniportal endoscopic or open lumbar spine surgery by analyzing position and gait metrics captured by a wearable sensor. We hypothesized that endoscopic spine surgery patients would experience a quicker return to mobility and spend more time standing, walking, and sitting and less time lying down compared with open spine surgery patients. Additionally, we predicted that endoscopic spine surgery patients would have a higher step count and a more efficient and stable gait.

MATERIALS AND METHODS

Study Design

This a prospective interventional study comparing the immediate postoperative position and gait metrics of 2 patient groups: endoscopic spine surgery patients and open spine surgery patients. The study was approved by the South Eastern Sydney Local Health District Ethics Committee with reference code 17/184. Informed consent was obtained from all patients before participation and submission for publication.

Study Participants

Study participants comprised 24 patients who presented to the NeuroSpine Clinic at Prince of Wales Private Hospital between April and July 2024. Participants were divided into 2 surgical intervention groups based on their symptoms and clinical diagnosis: (1) *Uniportal endoscopic lumbar decompression group:* 13 patients had single-level spinal stenosis and were suitable for a uniportal endoscopic lumbar decompression; they predominantly experienced nerve compression symptoms such as neurogenic claudication and did not need structural stabilization. (2) *Open posterior lumbar fusion group:* 11 patients had grade 1 single-level spondylolisthesis and were suitable for a fusion; they presented primarily with structural back pain due to segmental instability rather than isolated nerve compression.

After participants provided informed consent, an interview was conducted to obtain demographic characteristics, comorbidities, and baseline clinical characteristics. Patients provided a self-reported health rating on a scale from 0 to 100, and the EQ-5D questionnaire was conducted to measure health-related quality of life in 5 areas (mobility, self-care, activities of daily living, pain/discomfort, and anxiety/depression). These measures were used to compare the baseline health status of patients from both the endoscopic surgery group and open surgery group to ensure that there were no significant preoperative differences in perceived health status.

Overall, inclusion criteria included a clinical diagnosis of single-level lumbar spinal stenosis (for uniportal endoscopic lumbar decompression) or degenerative spondylolisthesis (for open posterior lumbar fusion) and insufficient improvement with nonsurgical treatment. Exclusion criteria included limited English proficiency interfering with consent or completion of questionnaires, inability to walk independently, or the presence of serious concurrent spinal pathologies.

Procedure

Both uniportal endoscopic lumbar decompression and open posterior lumbar fusion procedures were performed under general anesthesia without muscle paralysis. For endoscopic decompression procedures, a uniportal interlaminar approach was used for lateral recess stenosis, while a uniportal transforaminal approach was used for foraminal stenosis. Pain management protocols for both surgeries were similar, utilizing a multimodal approach including nonopioid analgesics, adjunct medications, and short-term opioids as needed.

After surgery, a wireless wearable sensor was placed at the center of the patient's chest below the jugular notch and secured with a dressing and medical tape (Figure 1). Both groups were encouraged to begin mobilizing early in the immediate postoperative period to promote recovery and reduce the risk of complications. However, patients undergoing endoscopic lumbar decompression were able to mobilize more freely with minimal restrictions, while patients undergoing open posterior lumbar fusion had more restrictions on movement, including avoiding bending, twisting, or lifting, to ensure proper healing and stabilization of the fusion site. For 48 hours postsurgery, the sensor recorded continuous measurements of position metrics, average daily step count, and base gait metrics. From the base gait metrics, derivative gait metric scores were calculated. Definitions of these variables are provided (Table 1).

Wearable Device

The wireless wearable sensor (32 mm diameter and 14 mm thick) used in the study was a custom device developed by Genesys Electronic Design (Sydney, Australia). The inertial measurement unit was BMF055, a 9-axis motion sensor developed by Bosch Sensortec (Kusterdingen, Germany). The inertial measurement unit contains a triaxial 14-bit accelerometer, 16-bit gyroscope, and geomagnetic sensor. Data captured by the sensor were transferred to an iOS smartphone

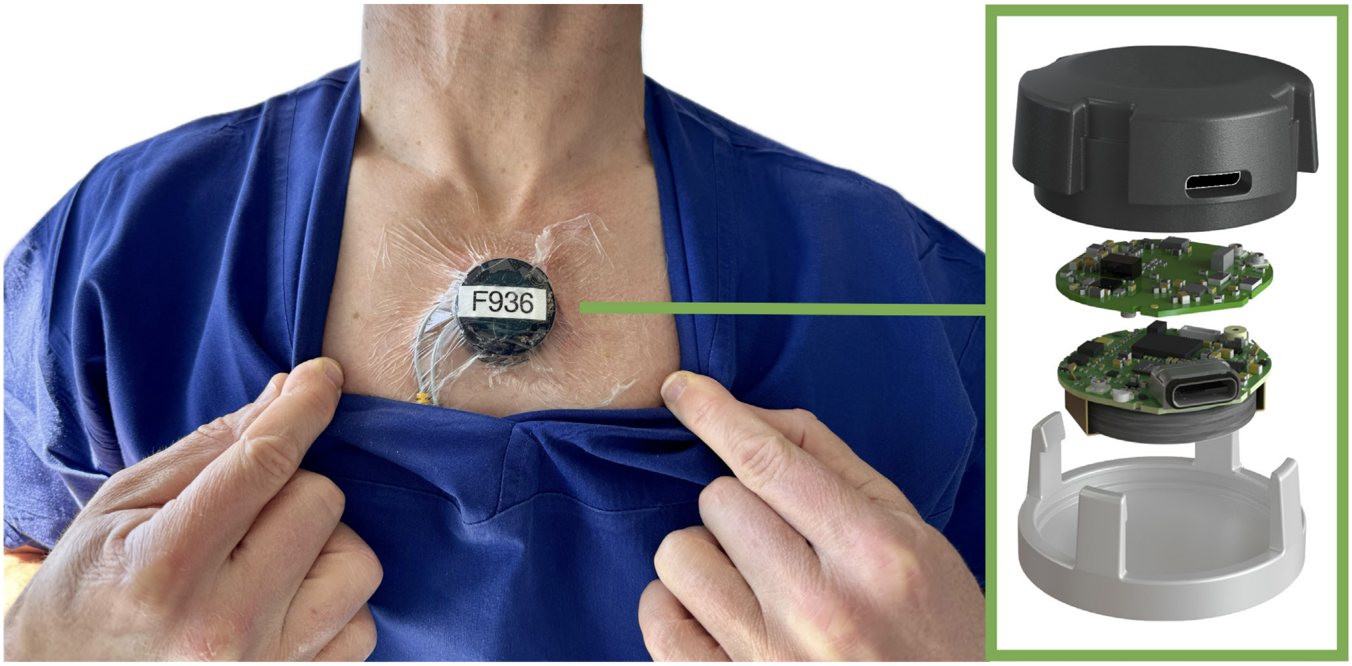

Figure 1. Wearable sensor developed by Genesys Electronic Design (Sydney, Australia) placed at the center of the chest below the jugular notch.

Table 1. Definition of metrics used in the present study.

Metric	Definition (units)
Position metrics	
Standing/walking	Time spent standing or walking (%)
Sitting	Time spent sitting (%)
Lying	Time spent lying (%)
Steps	
Daily step count	Average steps walked per day
Base gait metrics	
Gait velocity	Distance traveled per second (m/s)
Step length	Distance between 2 consecutive contacts of any foot with the ground (m)
Step time	Time between 2 consecutive contacts of any foot with the ground (s)
Double support	Percentage of time where both feet are in contact with the ground (%)
Derivative gait metrics	
Symmetry score	Gait symmetry index (score from 0–100), calculated as the sum of the 3 components below. • Gait velocity (m/s) • Step time asymmetry: step-to-step variability in step time (ms) • Step length asymmetry: step-to-step variability in step length (cm)
Gait velocity variability score	Step-to-step variability of gait velocity, calculated as the coefficient of variation (CoV): $\text{CoV} = \frac{\text{SD of gait velocity}}{\text{mean of gait velocity}} \times 100$
WORM score	Quantifies the stability, or "figure-of-8" motion of a subject's trunk during walking as an indicator of falls-risk with exact calculations by Mobbs et al.[23]

Abbreviation: WORM, walking orientation randomness metric.
Note: Position metrics, steps, and base gait metrics are directly calculated by the sensor. Derivative gait metrics are mathematically derived from the base gait metrics and are not directly calculated by the sensor. Symmetry is related to differences between the left and right leg. Variability is related to differences in gait velocity between each step.

application. The data were then converted into interpretable metrics.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 27.0 (IBM, New York, USA). The normality of variables was assessed using the Shapiro-Wilk test and visual inspection of histograms. The level of statistical significance was $P = 0.05$. Descriptive statistics were calculated for preoperative variables. Differences in preoperative variables and postoperative metrics between endoscopic and open spine surgery patients were assessed using the Mann-Whitney U test for non-normally distributed data or the independent samples t test (2-tailed) for normally distributed data. Welch's correction was applied for variables with unequal variance. Fisher's exact test was conducted to assess the association between patients' mobility levels and the day of discharge. A minimum sample size for significance was not calculated due to the paucity of data.

RESULTS

Twenty-eight patients were initially eligible and completed baseline assessments. One patient removed the sensor due to slight irritation from the medical tape. Three results were not included due to a sensor data retrieval error. Therefore, a total of 24 patients, 13 patients who underwent uniportal endoscopic spine

Table 2. Demographic and clinical characteristics of the endoscopic and open surgery participants.

Variable	Endoscopy (*n* = 13)	Open (*n* = 11)	*P*
Continuous variables, mean ± SD			
Age, y	66.85 ± 16.94	61.82 ± 11.54	0.414
Height, cm	168.85 ± 10.73	172.00 ± 10.21	0.422
Body mass, kg	81.92 ± 19.45	83.27 ± 17.46	0.861
Categorical variables, *n* (%)			
Female	6 (46.2)	5 (45.5)	-
Smoking	1 (7.7)	1 (9.1)	-
Diabetes	3 (23.1)	1 (9.1)	-
Hypertension	5 (38.5)	4 (36.4)	-
Falls in the past 12 months	3 (23.1)	1 (9.1)	-
Hip/knee pain	4 (30.8)	5 (45.5)	-
Back/knee pain	13 (100)	11 (100)	-
Walking aids	4 (30.8)	1 (9.1)	-
Health rating, 0–100, mean ± SD	83.08 ± 6.63	84.27 ± 5.73	0.644
EQ-5D score, mean ± SD or median (IQR)	0.770 ± 0.851	0.800 (0.040)	0.392
Mobility, *n* (%)			
No problem	0 (0)	0 (0)	-
Slight	7 (53.8)	1 (9.1)	
Moderate	4 (30.8)	5 (45.5)	
Severe	2 (15.4)	5 (45.5)	
Unable	0 (0)	0 (0)	
Self-care, *n* (%)			
No problem	0 (0)	0 (0)	-
Slight	7 (53.8)	7 (63.6)	
Moderate	4 (30.8)	2 (18.2)	
Severe	2 (15.4)	2 (18.2)	
Unable	0 (0)	0 (0)	
Activities of daily living, *n* (%)			
No problem	1 (7.7)	0 (0)	-
Slight	7 (53.8)	8 (72.7)	
Moderate	4 (30.8)	3 (27.3)	
Severe	1 (7.7)	0 (0)	
Unable	0 (0)	0 (0)	
Pain/discomfort, *n* (%)			
None	0 (0)	0 (0)	-
Slight	3 (23.1)	4 (36.4)	
Moderate	8 (61.5)	7 (63.6)	
Severe	2 (15.4)	0 (0)	
Extreme	0 (0)	0 (0)	
Anxiety/depression, *n* (%)			
None	12 (92.3)	10 (90.9)	-
Slight	1 (7.7)	0 (0)	
Moderate	0 (0)	1 (9.1)	
Severe	0 (0)	0 (0)	
Extreme	0 (0)	0 (0)	

Note: For continuous variables, mean ± SD was reported for normally distributed data, and median (interquartile range [IQR]) was reported for non-normally distributed data. For categorical variables, frequency counts (*n*) and percentages (%) were reported.

surgery for spinal stenosis and 11 patients who underwent open spine surgery for spondylolisthesis, were included in the study. There were no nerve root complications or dural injuries in this trial cohort.

Patient Characteristics

There was no significant difference in age, height, or body mass of endoscopic and open spine surgery participants (age: 66.85 vs 61.82 years, $P = 0.414$; height: 168.85 vs 172.00 cm, $P = 0.422$; body mass: 81.92 vs 83.27 kg, $P = 0.861$). There was no significant difference in comorbidities and baseline clinical characteristics (smoking status, diabetes, hypertension, falls, pain, and walking aids), preoperative health ratings, and EQ-5D scores between the 2 groups as shown in Table 2.

Comparison of immediate postoperative data is outlined in the following paragraphs and presented in Table 3.

Position Metrics

Endoscopic spine surgery patients spent a significantly larger proportion of time sitting (52.31% vs 27.82%; $P = 0.022$) and smaller proportion of time lying down (26.92% vs 53.18%; $P = 0.006$) compared with open spine surgery patients. There was no significant difference in the proportion of time spent standing

Table 3. Comparison of immediate postoperative position metrics, step count, and gait metrics of endoscopic and open surgery patients.

	Endoscopy (n = 13)	Open (n = 11)	Group Difference (Endoscopy—Open)		
Variable	**Mean ± SD or Median (IQR)**		**95% CI**	**%**	***P***
Position metrics					
Stand/walk, %	20.62 ± 12.76	19.00 ± 10.43	−8.37; 11.60	8.526	0.741
Sit, %	52.31 ± 25.43	27.82 ± 22.69	3.91; 45.07	88.03	0.022[a]
Lie, %	26.92 ± 18.06	53.18 ± 24.31	−44.21; −8.31	−49.38	0.006[a]
Steps					
Daily step count	475.91 ± 254.94	244.00 ± 105.54	50.19; 413.62	95.05	0.015[a]
Gait Metrics					
Gait velocity, m/s	0.966 ± 0.831	0.831 ± 0.629	0.061; 0.208	16.25	0.001[a]
Step length, m	0.650 ± 0.141	0.607 (0.088)	−0.146; 0.158	0.071	0.888
Step time, s	0.680 ± 0.059	0.675 (0.077)	−0.182; 0.118	0.741	0.423
Double support, %	21.60 (8.85)	29.88 ± 4.92	−11.10; 0.00	−27.71	0.046[a]
Symmetry score	87.47 ± 3.50	85.01 (3.67)	−2.58; 5.13	2.821	0.277
Variability score	11.82 ± 5.89	22.43 ± 6.77	−17.15; −4.07	−47.30	0.004[a]
WORM score	0.810 ± 0.82	0.817 (0.415)	−0.58; 0.57	−0.857	0.673

Abbreviation: WORM, walking orientation randomness metric.
Note: Mean ± SD was reported for normally distributed data, and median interquartile range [IQR]) was reported for non-normally distributed data.
[a]Statistically significant result ($P < 0.05$).

or walking. A comparison of position metrics is represented in Figure 2.

Step Count

Endoscopic spine surgery patients began walking earlier and had a significantly higher daily step count (approximately double) compared with open spine surgery patients (475.91 vs 244.00; $P = 0.015$).

Gait Metrics

Endoscopic spine surgery patients had a significantly higher gait velocity (0.966 m/s vs 0.831 m/s; $P = 0.001$), lower double support percentage (21.60% vs 29.88 %; $P = 0.046$), and lower gait velocity variability score (11.82 vs 22.43; $P = 0.004$) compared with open spine surgery patients. There were no significant differences in step length, step time, symmetry, or walking orientation randomness metric score between the 2 groups.

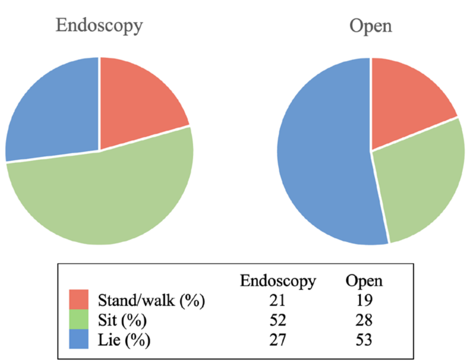

Figure 2. Pie charts representing the mean proportion of time endoscopic and open spine surgery patients spent in each position (standing/walking, sitting, and lying). Differences in postoperative metrics between the 2 groups were assessed using the Mann-Whitney *U* test for non-normally distributed data or the independent samples *t* test (2-tailed) for normally distributed data.

A comparison of endoscopic and open spine surgery patient gait metrics is represented in Figure 3.

Mobility and Discharge

There was a moderately strong association between mobility and time of discharge ($\varphi = 0.580$; $P = 0.007$). Among people who spent more than 50% of their time sitting/standing, 78.6% were discharged by postoperative day 2, and 80.0% of people who spent less than 50% of time sitting/standing were discharged after postoperative day 2. For a person with more than 50% mobility, the odds of being discharged by postoperative day

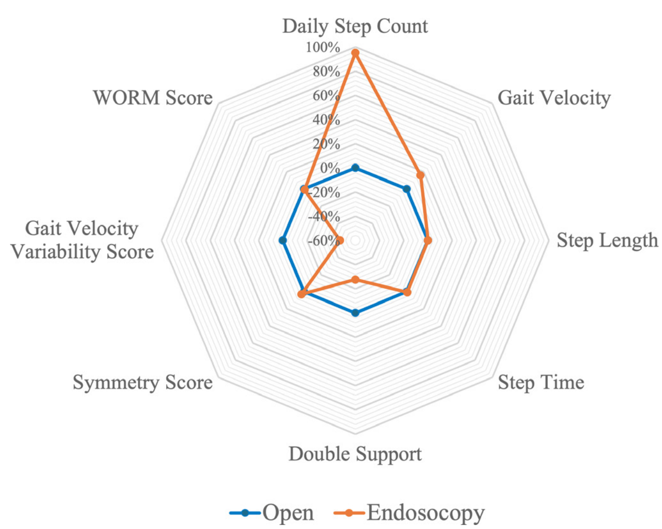

Figure 3. Radar plot comparing the gait metrics of endoscopic and open spine surgery patients. Values represent the percentage difference between endoscopic (orange) and open (blue) spine surgery patient gait metrics, with open spine surgery patient values placed at 0%. Differences in postoperative metrics between the 2 groups were assessed using the Mann-Whitney *U* test for non-normally distributed data or the independent samples *t* test (2-tailed) for normally distributed data.

2 were 14.67 times more likely than being discharged after postoperative day 2.

DISCUSSION

Regardless of the approach, lumbar spine surgery aims to relieve symptoms and improve functional mobility. Immediate postoperative position and gait metrics can provide insight into patients' functional outcomes and recovery after surgery. Consequently, the present study aims to compare the mobility of patients following either a single-level uniportal endoscopic lumbar decompression or open posterior lumbar fusion through objective and continuous measurements of position, step count, and gait metrics from a wearable sensor. The results support initial hypotheses that endoscopic spine surgery patients would experience a quicker return to mobility and spend less time lying down compared with open-surgery patients. Additionally, endoscopic spine surgery patients had a higher step count and a more efficient and stable gait compared with open spine surgery patients.

Position Metrics

The increased proportion of time that open spine surgery patients spend lying down suggests that these patients may require more time to recover before their mobility levels increase, and they are able to engage in more activities, resulting in a longer hospital stay. These findings are consistent with those of Xiao et al,[6] who found that endoscopic spine surgery patients have less bed rest, and Ahn et al,[24] who found that hospital stay was significantly shorter for endoscopic spine surgery patients compared with open spine surgery patients (2.1 vs 6.1 days; $n = 198$; $P < 0.05$). However, the present study provides a more detailed understanding of the position that patients tend to occupy during the immediate postoperative period. This study found that open spine surgery patients spent significantly more time lying down and less time sitting in the first 48 hours after surgery compared with endoscopic spine surgery patients. Sitting requires adequate comfort, stability, and functional mobility for patients to maintain an upright posture.[25] Longer time spent lying down may indicate patients' increased pain and discomfort due to greater tissue damage and muscle dissection.[4,5] The similar proportion of time patients spent standing or walking in both groups does not support the initial hypothesis that endoscopic spine surgery patients would spend a greater proportion of time standing or walking. This may be attributed to daily physiotherapy walking sessions being a standard component of postoperative care for all patients.

Step Count

The present study expands upon current literature by demonstrating that daily step count was higher for endoscopic spine surgery patients. This finding highlights that patients who have undergone an endoscopic lumbar decompression may have an increased ability and willingness to walk compared with patients who have undergone an open posterior lumbar fusion, who require more time to regain mobility. This is likely due to the longer healing process following open surgery, associated with larger incisions and more extensive muscle and soft tissue damage.[4,5] The structured nature of walking sessions for both endoscopic and open spine surgery patients ensured that all patients spent time walking each day, leading to a similar proportion of time standing/walking for both groups. However, endoscopic patients' higher step count suggests they walked more during and/or outside of these sessions, likely attributable to increased functional mobility and reduced pain.[4,5]

Gait Metrics

Patients who underwent endoscopic spine surgery had higher gait velocity, increased stability (lower double support percentage), and reduced gait velocity variability compared with open spine surgery patients. Gait velocity has been well documented as an indicator of functional recovery after surgery.[15,16] The higher gait velocity of endoscopic spine surgery patients suggests improved functional mobility and enhanced ability to perform activities. The increased double support time of open-surgery patients may reflect a more cautious gait pattern where patients spend more time with both feet on the ground when walking, which suggests increased postoperative pain and reduced strength and confidence to comfortably shift their weight onto 1 leg. The higher gait velocity variability score for open spine surgery patients can be attributed to impaired balance and increased pain, resulting in a hesitant and uneven gait. Variability scores may also be higher in open spine surgery patients due to their discomfort and subsequent fear of falling, resulting in a need to adjust their speed.[26]

The differences in gait patterns between the 2 groups suggest that patients may have a more efficient and stable gait when walking following endoscopic spine surgery compared with open spine surgery in the immediate postoperative period, likely attributable to reduced pain from less tissue damage and muscle dissection. These objective findings align with the subjective findings by Chen et al,[17] who reported that immediate postoperative VAS pain scores improved for endoscopic spine surgery patients but worsened for open spine surgery patients (3.5 vs −0.56; $n = 43$; $P < 0.0001$). Patients who undergo endoscopic spine surgery can walk more comfortably, which suggests a faster recovery and return to activities. These findings can guide rehabilitation resources as endoscopic spine surgery patients may require less formal postoperative rehabilitation. Conversely, open surgery patients may require more intensive rehabilitation to gain substantial improvement in mobility.

Mobility and Discharge

The correlation between mobility and discharge may be used to establish a threshold for determining when patients are ready for discharge based on their mobility levels. This also suggests that hospital costs can be decreased by implementing surgical techniques, such as endoscopic spine surgery, that can promote quicker return to mobility and shorter hospital stay.

Overall, objective and continuous monitoring of immediate postoperative mobility and gait patterns allowed for the identification of key differences between the recovery of endoscopic and open spine surgery patients. The quicker return to mobility of endoscopic spine surgery patients compared with open spine surgery patients is evidenced by a reduced proportion of time lying down, higher daily step count, higher gait velocity, lower double support percentage, and lower gait velocity variability score in the first 48 hours after surgery.

Strengths and Limitations

The present study uses continuous measurements of patients' position, step count, and gait metrics instead of single sets of data, allowing for better comparisons and identification of postoperative trends. The study highlights objective differences between open and endoscopic spine surgery patient recovery, rather than relying on subjective data. A small, lightweight, chest-based sensor was used for easy attachment, precise positioning, and minimal interference with mobility, compared with devices placed on the lower back or lower limbs.

A limitation of this study was the lack of randomization in assigning patients to the 2 surgical intervention groups. Instead, the surgical intervention was determined based on each patient's clinical diagnosis and symptoms. Specifically, patients with predominant nerve compression symptoms and a diagnosis of single-level lumbar spinal stenosis underwent an endoscopic lumbar decompression, while patients with mostly mechanical back pain and a diagnosis of grade 1 spondylolisthesis underwent an open posterior lumbar fusion. However, both groups had similar demographic characteristics, comorbidities, and baseline clinical characteristics, health rating, and EQ-5D scores, indicating that there were no significant preoperative differences in perceived health status that would influence postoperative recovery.

Another limitation was the varied time of day when the surgery was performed, which can affect postoperative mobility data. For example, if a procedure was performed later in the day, the time that patients spend lying down immediately after surgery may coincide with their usual sleep time. However, if a procedure was performed earlier in the day, they may spend time lying down immediately after surgery in addition to their usual sleep time. Patients' mobility was monitored for a maximum of 48 hours postoperatively, which prevents assessment of long-term trends in mobility and recovery. Without long-term monitoring, the study cannot assess the sustainability of endoscopic spine surgery patients' earlier mobility. The recruitment process of participants was limited to a single-center and single-surgeon practice, and the senior neurosurgeon is also highly experienced in endoscopic spine surgery, limiting the generalizability of findings.

Additionally, patients undergoing endoscopic lumbar decompressions were able to mobilize more freely with minimal restrictions, while those undergoing open posterior lumbar fusions had more restrictions on movement, such as avoiding bending, twisting, or lifting, to ensure proper healing and stabilization of the fusion site. These differences in mobility protocols could have impacted mobility outcomes and recovery patterns between the 2 groups.

Future Research

Multicenter studies with diverse surgical teams and larger sample sizes can improve generalizability. Extended monitoring is also warranted to confirm whether differences in immediate postoperative recovery between endoscopic and open surgery patients are sustained for long-term recovery. Wearable devices may be used in further studies for predictive modeling of postoperative outcomes and the development of spine surgery recovery trajectories, allowing for more targeted rehabilitation and prompt intervention for deviations in patient recovery.

CONCLUSION

The present study is a pilot study comparing the recovery of uniportal endoscopic and open spine surgery patients by analyzing objective and continuous position and gait metrics captured by a wearable sensor. Uniportal endoscopic spine surgery patients experienced a quicker return to mobility, with less time lying down, higher step count, faster gait velocity, lower double support percentage, and reduced variability. These findings highlight the faster recovery of endoscopic patients, which can guide resource allocation toward spine endoscopy training, more widespread implementation, and advancement to optimize patient outcomes. Further research with larger sample sizes and long-term monitoring is needed to confirm the persistence of these trends.

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