# Objective evaluation of postoperative changes in real-life activity levels in the postoperative course of lumbar spinal surgery using wearable trackers

**Masahiro Inoue** (masain_96@hotmail.com)
Department of Orhtopaedic surgery, Graduate School of Medicine, Chiba University
https://orcid.org/0000-0002-9518-9189

**Sumihis Orita**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University

**Kazuhide Inage**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University

**Miyako Suzuki**
Department of Orthopaedic Surgery, Graduate school of Medicine, Chiba University

**Kazuki Fujimoto**
Department of Orthopaedic Surgery, Saiseikai Narashino Hospital

**Yasuhiro Shiga**
Departoment of Orthopaedic Surgery, Graduate school of Medicine, Chiba University

**Hirohito Kanamoto**
Kanamoto Orthopaedic Clinic

**Koki Abe**
Department of Orhotpaedic Surgery, Graduate school of Medicine, Chiba University

**Hideyuki Kinoshita**
Department of Orthopaedic Surgery, Chiba Cancer Center

**Masaki Norimoto**
Department of Orthopaedic Surgery, Graduate school of Medicine, Chiba University

**Tomotaka Umimura**
Department of Orthopaedic Surgery, Graduate school of Medicine, Chiba University

**Takashi Sato**
Deartment of Orthopaedic Surgery, Graduate school of Medicine, Chiba University

**Masashi Sato**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University

**Masahiro Suzuki**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiiba University

**Keigo Enomoto**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University

**Yawara Eguchi**
Department of Orthopaedic Surgery, Shimoshizu National Hospital
**Tsutomu Akazawa**
Department of Orthopaedic Surgery, St. Marianna University School of Medicine
**Yasuchika Aoki**
Department of Orthopaedic Surgery, Eastern Chiba Medical Center
**Yohei Kawasaki**
Biostatistics Section, Clinical Reserch Center, Chiba University Hospital
**Seiji Ohtori**
Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University

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Abstract

Background: Lumbar spinal disease causes disabilities in performing daily activities. Operative treatments are aimed at pain relief and rapid return to routine activity. Patient-based outcome measures are used to evaluate pathologies and therapeutic effects associated with lumbar spinal disease. However, it remains unknown how much such treatment improves the activity levels. The purpose of current study was to evaluate the changes in activity levels before and after lumbar spinal surgery using a wearable activity tracker and to compare the relationship between the results and the patient-based outcomes.

Methods: Sixty patients who underwent lumbar surgery were studied. The physical activity of participants was objectively evaluated using a wearable Micro-Motion logger system (Actigraph). We measured the amount of activity before and at 1, 3, 6, and 12 months after the surgery to evaluate postoperative changes. Additionally, the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire, Oswestry Disability Index, Roland-Morris Disability Questionnaire and Visual analog scale were used to assess patient-based outcomes of pain and ADL-related scores and the corresponding relationships with the actual activity levels were evaluated.

Results: The amount of actual activity decreased significantly 1 month after the surgery compared to that during the preoperative period, which then improved after 3 months postoperatively ($p < 0.01$). Furthermore, there was a significant improvement 6 months after the surgery compared to that during the preoperative period ($p < 0.05$). Moreover, the change in activity amount for each period was strongly correlated, regardless of the period. In contrast, a significant improvement was observed at 1 month after the surgery in almost all items of the patient-based questionnaires ($p < 0.05$).

Conclusions: The objective activity tracker demonstrated that lumbar surgery results in the amount of activity decreasing 1 month just after surgery followed by gradual postoperative recovery within 3 months. In contrast, patient-based outcomes showed improvement in 1 month, which was significantly different from the change in actual activity, indicating the gap between the patient-oriented clinical score and their actual activities.

# Background

Spinal disorders have a greater burden than most other commonly detected medical conditions. Especially in the elderly population, spinal disorders are more prevalent and may have a more significant impact on health status [1]. Pathological state can sometimes cause disability in daily activities, requiring operative as well as conservative treatment. These treatments are aimed at relief of pain and rapid return to routine activity. However, it remains unknown how much the treatment improves the activity level.

Patient-based outcome measures are used to evaluate pathology and therapeutic effects associated with lumbar spinal disease [2-5]. While these measurements have the merit of being simple and allow for the evaluation of multiple items, their disadvantage is that objective evaluation can be difficult due to the self-answering design and adventitious missing values in these measurements [6]. Therefore, more objective assessment procedures should be explored and applied to precisely evaluate the postoperative course.

In the field of biophysical monitoring, wearable sensors to capture an individual's movements and physical activity have been attracting attention with respect to health outcome measurements [7]. These devices objectively collect and store measurements related to the patients' daily living behavior, such as exercise, sleeping habits, and vital sign changes. Movement-related acceleration (which in turn correlates with energy consumption) was monitored using accelerometers [8,9]. In an objective assessment using wristwatch-type wearable trackers, it was reported that patients with rheumatoid arthritis and lower back pain had decreased activity levels compared to healthy participants, and it seemed that the amount of daytime activity reduced due to disease and pain [10,11]. However, there are few reports on changes in the amount of actual activity before and after lumbar surgery of patients. Therefore, the current study aimed to evaluate changes in real-life activity levels before and after lumbar spinal surgery using a wearable activity tracker, and to compare the relationship between the results and patient-based questionnaire outcomes.

# Methods

### *Study design*

In the current prospective observational study, patients scheduled to undergo surgical treatment for lumbar spinal disease were consecutively recruited at a single institution. The study was approved by the ethics committee of our institution (No.2428). All participants were informed of the purpose of the study, received information, and provided written consent.

### *Inclusion and exclusion criteria*

The patients were 49 to 88 years old and underwent surgeries at our hospital for lower back pain and lower limb symptoms due to lumbar degenerative disease. The diagnosis of lumbar degenerative disease was made by the treating spine surgeon based on the clinical evaluation, radiographic, and magnetic resonance imaging findings. The surgeries were performed by two spinal surgeons.

Patients with illnesses or symptoms that could have affected the amount of activity or questionnaire results were excluded after interviews and physical examinations. The exclusion criteria were as follows: (1) presence of motor weakness or deficit; (2) presence of severe painful osteoarthropathy; (3) coexisting gait disorder associated with a disease other than degenerative lumbar disease; and (4) a psychiatric or cognitive disorder.

### *Actual physical activity measurement*

The objective physical activity of participants was evaluated using the Actigraph® Micro-Motion logger (Ambulatory Monitors Inc., Ardsley, NY, USA), a wristwatch-shaped waterproof omnidirectional accelerometer (size: 2.5×0.9 cm; weight: 14 g), with which acceleration is transduced by a piezoelectric element with a sensitivity of 0.01 G/min, and these voltages were recorded and averaged in 1-min epochs. The Actigraph is an evidence-based tracking system designed for continuous 24-h monitoring and analysis of activity levels and movement counts during both waking and sleeping hours. Each participant wore the logger on the non-dominant wrist for 1 week for each time point, allowing us to calibrate the data for daytime activities (between 8 AM to 6 PM). Data were collected and analyzed using the dedicated Action-W software (version 2.4.15), based on the validated algorithms [12]. Outcome measures included items reported in previous studies for comparisons [7,12,13]: the proportional-integrating mode (PIM), the total amount of movement in a 1-min epoch. The PIM provides a high-resolution measurement (range: 0–65,000) of the area under the rectified analog signal, which is designed to quantify more sedentary types of motions. We measured the mean active count (MAC) in PIM as the activity amount before surgery and 1, 3, 6, and 12 months after surgery.

### *Patient-based outcome measurements*

Clinical symptoms were evaluated using the visual analog scale (VAS) score for lower back pain, leg pain, and leg numbness ranging from 0 (no pain) to 100 mm (extreme pain), the Oswestry Disability Index (ODI) (0-100 points), the Roland-Morris Disability Questionnaire (RDQ) (0–24 points), and the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire (JOABPEQ). JOABPEQ, RDQ, and ODI are all Japanese questionnaires, and their validation with the original language has been verified. The first two items, VAS and ODI, can be used to evaluate lumbar pain, leg pain, and numbness, but these do not directly measure symptoms that occur in association with certain postures and activities. The RDQ was designed specifically to measure the impact of lumbar pain on the quality of life. The JOABPEQ includes 25 questions based on the RDQs and Short Form 36 (SF-36). Scores were calculated based on the answers to questions in five domains: pain-related disorders, lumbar spine dysfunction, gait disturbance, social life dysfunction, and psychological disorders. The score for each domain was calculated according to official guidelines and ranged from 0 to 100 points with lower scores indicating greater symptom severity, which is deemed proportional to the patient's clinical condition [14,15].

### *Statistical analysis*

To evaluate the change in the activity amount, the postoperative MAC divided by the preoperative MAC multiplied by 100 was calculated as the percentage change in each period. First, the percentage change before and after the surgery was calculated with a linear mixed model for repeated measures. Additionally, to evaluate the relationship between changes in the amount of activity for each period, a single regression analysis was performed using the former as the explanatory variable and the latter as the objective variable in the two periods.

Next, to evaluate the transition of patient-based outcome as well as activity level, the relationship between the preoperative and postoperative score was evaluated in each item using the Wilcoxon signed-rank test.

All data are reported as means ± standard deviations, unless otherwise indicated. We defined the significance level at 5% and used SAS Version 9.4 for all statistical analyses in the current study.

# Results

The current study included 60 patients (30 men and 30 women). The mean age was 70.7 ± 8.4 years. The mean BMI was 24.5 ± 4.4 kg/m². The mean duration of morbidity was 50.9 ± 49.9 (min 2, max 180) months. The disease breakdown included 42 cases of lumbar spinal stenosis, 13 cases of lumbar spondylolisthesis, and five cases of degenerative lumbar scoliosis. The surgical procedure included 26 cases of decompression surgery and 34 cases of fusion surgery (Table 1).

### *Comparison of the activity amounts before and after the surgery*

Some data were not available for each period due to wearable device failures, incomplete questionnaires, and forgotten patient visits. The percentage change of the mean active counts compared to the baseline in each period were 92.3 ± 5.6 at 1 month postoperatively, 108.2 ± 7.2 at 3 months postoperatively, 120.5 ± 9.4 at 6 months postoperatively, and 127.9 ± 13.2 at 12 months postoperatively (Table 2). The MAC decreased significantly at 1 month after the surgery compared to that during the preoperative period and improved after 3 months postoperatively. At 12 months postoperatively, there was a significant increase even compared to that at 3 months ($p < 0.01$). Compared to the preoperative period, the MAC increased significantly at 6 and 12 months postoperatively ($p < 0.05$) (Fig 1). Regarding the relationship of change in the MAC in each period, correlation was observed in all periods in a single regression analysis. Among them, a strong correlation was found between the preoperative and other periods ($p < 0.01$), and the strongest correlation was between 1 month postoperatively and 3 months postoperatively ($r^2 = 0.792$, $p < 0.001$) (Table 3).

### *Comparison of the patient-based questionnaire before and after the surgery*

For the patient-based questionnaires, the scores were significantly improved in most of the periods compared to those during the preoperative period. For JOABPEQ, pain-related disorder significantly improved (56.5 ± 40.5 at 1 month, 71 ± 34.9 at 3 months) postoperatively compared to that during the preoperative period (34.3 ± 30.2; $p < 0.05$). There was little change after 3 months. This was similar to gait disturbance and social life dysfunction. Psychological dysfunction was significantly improved at 1 month after the surgery and there was no significant change after that. In contrast, lumbar spine dysfunction showed improvement of score 3 months after the surgery. As for ODI, RDQ, and VAS, we found a significant improvement in the scores at 1 month after the surgery ($p < 0.01$). The ODI and RDQ scores further improved at 12 months, while lower back pain and lower limb numbness showed a slight increase with the VAS (Table 4).

# Discussion

Using the wearable activity trackers, actual changes in activity amount before and after lumbar surgery were measured. The amount of activity decreased 1 month after surgery followed by gradual recovery within 3 months after the surgery, and there was a significant improvement 6 months after the surgery. Moreover, the actual change in activity amount for each period was strongly correlated regardless of the period. In contrast, for patient-based questionnaires, improvement was significant 1 month after the surgery in almost all items, and thereafter change was not significant.

There are several reports on the change in postoperative physical activity using accelerometers. In joint surgery, Bolink et al. reported that the physical performance improved 1 year after total knee arthroplasty compared to that before surgery using an inertial measurement unit [16]. In contrast, Smuck reported that in 28 cases of lumbar spinal canal stenosis, the amount of activity remained unchanged between before surgery and 6 months postoperatively [17]. In our study, the actual amount of activity showed a temporal decrease 1 month after surgery, while it gradually recovered 3 months after surgery. Furthermore, the measured actual activity significantly improved 6 months after surgery compared to the preoperative period. We considered that the amount of activity decreased with pain and physical fitness due to surgical invasion at the point of 1 month after surgery, and it increased with improvement of pain and symptoms after 3 months. The transition of the activity amount of each patient strongly correlated in any period regardless of the preoperative symptom and surgical procedure. Since the change in activity from 1 to 3 months after surgery was very strongly correlated, the reduction of activity amount due to surgical invasion in the early postoperative period and the subsequent improvement showed similar trends regardless of the patient. This implies that the amount of postoperative activity might be predicted from the amount of preoperative activity.

Regarding the trend of subjective patient-based outcomes, improved scores were observed at 1 month after the surgery for all items. Most items after 3 months postoperatively became constant, and the scores were not improved. This result was similar to a previous report [18] but deviated from our data of the actual change in physical activity measured by a wearable activity tracker. There are some reports that low back pain affects the amount of activity [19, 20], but especially, VAS, showing clinical symptoms, improved on the early postoperative days, and it was very different from the change of activity amount. Furthermore, this result was different from previous reports that low back pain affects activity. This suggests that pain and clinical symptoms may contribute to a decrease in the activity level, but that the postoperative improvement of symptoms is not directly linked to improvement in activity amount.

The advantage of our study is that we obtained frequent objective data using wearable terminals from short to medium-term and showed a more detailed postoperative course.

Moreover, it was shown that there was a dissociation between the actual perioperative change of the amount of activity and the change of subjective evaluation using traditional measurements, which should be considered in the clinical situation to build more effective treatments for lower back pain patients.

There were some limitations to our study. First, since the diseases and surgical procedures of patients participating in the study were different, this influence could not be excluded. However, we consider that the change in activity amount before and after surgery was strongly correlated even if the diseases and surgical procedures were different, and it shows that a similar recovery process is followed for lumbar spinal surgery in general. Nevertheless, we plan to further investigate the change in activity amount for each disease and surgical procedure. Next, we could not evaluate changes in patient satisfaction, medical cost, and related factors as an influence on activity improvement, which would be evaluated in the future. Furthermore, the sample size was small, and we were not able to consider age and sex separately for analysis. Therefore, it is necessary to involve larger groups in the future.

In the current study, the objective evaluation using a wearable activity tracker was useful in evaluating the actual activities of the postoperative patients, and made it possible to evaluate the actual quality of life before and after the surgery, which was difficult with only the traditional subjective patient-based outcomes.

# Conclusions

The objective activity tracker demonstrated that in lumbar surgery, the amount of activity decreased 1 month after the surgery with a gradual recovery within 3 months after the surgery. Moreover, the change in activity amount in each period was strongly correlated irrespective of the period, and the preoperative activity amount had a large influence on postoperative activity amount. In contrast, subjective patient-based outcomes showed improvement in 1 month, which was different from the change in actual activity, indicating that the traditional evaluation can lack in the ability to express the precise nuance of the actual activities in the postoperative patients.

# Abbreviations

ADL, activities of daily living; PIM, proportional-integrating mode; MAC, mean active count; VAS, visual analog scale; ODI, Oswestry Disability Index; RDQ, Roland- Morris Disability Questionnaire; JOABPEQ, Japanese Orthopaedic Association of Back Pain Evaluation Questionnaire; BL, baseline

# Declarations

### *Ethics approval and consent to participate*

The study was approved by the Research Ethics committees of Graduate School of Medicine, Chiba University (No.2428). All participants were informed of the purpose of the study, received information, and provided written consent.

### *Consent for publication*

All participants were informed of the purpose of the study, received information, and provided written consent for publication.

### *Availability of data and materials*

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### *Competing Interests*

The author declares that they have no competing interests.

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### *Authors' contributions*

MI, SuO, MiS, KI, KF, YS, HirK, KA, HidK, MN, TU, ST, MasasS, MasahS, KE, and SeO, designed the study and analyzed and/or interpreted the data. MI wrote the article and SuO, MiS, KI, YE, YA and SeO provided critical comments on the draft of the manuscript. All authors read and approved the final version of the manuscript.

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# Tables

**Table 1. Demographic data**

| | |
|---|---|
| No. of patients | 60 |
| Age, mean (range), yr | 70.7 ± 8.4 (49-88) |
| Sex (Male / Female) | 30/ 30 |
| Body mass index ($kg/m^2$) | 24.5 ± 4.4 |
| Duration of illness, (range), month | 50.9 ± 49.9 (2-180) |
| Diagnosis | |
| Lumbar spinal stenosis | 42 (70%) |
| Lumbar spondylolisthesis | 13 (22%) |
| Degenerative lumbar scoliosis | 5 (8%) |
| Surgical method | |
| Decompression | 26 (43%) |
| Fixation | 34 (57%) |

**Table 2. Adjusted loss in mean active count in patients with lumbar spinal surgery estimated with the mixed-model for repeated measures**

| | n | Mean active count, SD | percentage change from baseline, SD | Repeated measurement, SE |
|---|---|---|---|---|
| Baseline | 60 | 3474 ± 1698 | 100 | 100 |
| 1 month | 43 | 3279 ± 1673 | 90.9 ± 31.8 | 92.3 ± 5.6 |
| 3 months | 47 | 3547 ± 1700 | 104.2 ± 42.2 | 108.2 ± 7.2 |
| 6 months | 46 | 3777 ± 2017 | 111.6 ± 49.7 | 120.5 ± 9.4 |
| 12 months | 44 | 3912 ± 1879 | 125.6 ± 104.4 | 127.9 ± 13.2 |

**Table 3. Correlation between periods in mean active counts**

| | | Mean active counts | |
|---|---|---|---|
| | | R | p value |
| Baseline - | 1 month | 0.5113 | <0.001 |
| | 3 months | 0.5766 | <0.001 |
| | 6 months | 0.5712 | <0.001 |
| | 12 months | 0.4527 | <0.001 |
| 1 month - | 3 months | 0.7920 | <0.001 |
| | 6 months | 0.2911 | <0.001 |
| | 12 months | 0.4479 | <0.001 |
| 3 months - | 6 months | 0.4149 | <0.001 |
| | 12 months | 0.5288 | <0.001 |
| 6 months - | 12 months | 0.5869 | <0.001 |

**Table 4. Change of the patient-based questionnaire score**

| | Baseline | 1 month | 3 months | 6 months | 12 months |
|---|---|---|---|---|---|
| JOABPEQ | | | | | |
| Pain-related disorder | 34.3 ± 30.2 | 56.5 ± 40.5* | 71.0 ± 34.9* | 61.6 ± 36.8* | 67.7 ± 36.0* |
| Lumbar spine dysfunction | 46.8 ± 29.7 | 50.7 ± 29.4 | 58.3 ± 28.6* | 55.9 ± 32.5* | 63.4 ± 30.9* |
| Gait disturbance | 20.5 ± 20.3 | 42.1 ± 27.1* | 46.4 ± 30.2* | 45.9 ± 33.0* | 45.9 ± 30.2* |
| Social life dysfunction | 34.5 ± 17.8 | 44.9 ± 22.0* | 46.2 ± 20.4* | 45.1 ± 23.8* | 49.8 ± 22.9* |
| Phycological disorder | 38.0 ± 19.6 | 48.2 ± 17.6* | 48.3 ± 15.9* | 45.6 ± 18.2* | 47.0 ± 14.7* |
| ODI | 51.6 ± 16.2 | 35.8 ± 17.0* | 36.4 ± 19.4* | 37.0 ± 20.8* | 31.4 ± 19.5* |
| RDQ | 13.8 ± 4.6 | 9.8 ± 5.7* | 9.1 ± 7.1* | 9.5 ± 7.0* | 8.1 ± 5.9* |
| VAS | | | | | |
| Low back pain | 7.3 ± 2.4 | 3.7 ± 3.3* | 2.9 ± 3.0* | 3.0 ± 2.7* | 3.7 ± 3.2* |
| Lower limb pain | 7.4 ± 2.6 | 3.5 ± 3.4* | 3.1 ± 3.0* | 3.2 ± 3.3* | 3.2 ± 3.4* |
| Lower limb numbness | 7.2 ± 2.6 | 3.2 ± 3.1* | 3.6 ± 3.4* | 3.8 ± 3.4* | 4.5 ± 3.4* |

* $p < 0.05$ as compared with baseline

# Figures

Fig.1

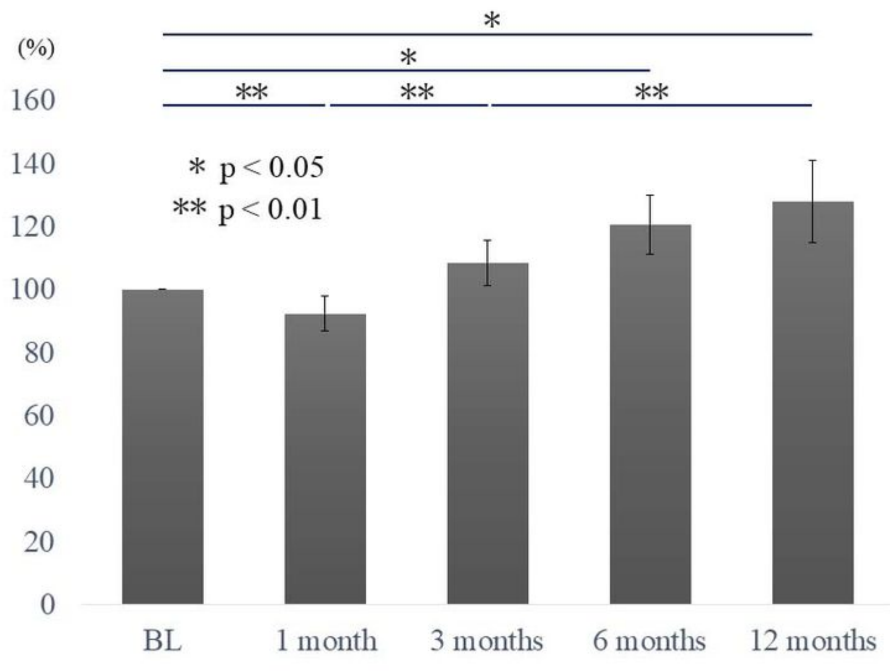


**Figure 1**

Percentage change before and after surgery Activity amount was significantly lower at 1 month after the surgery compared to the other time points. In addition, at 6 and 12 months postoperatively, the amount of actual activity improved significantly compared to the baseline. BL, baseline