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ORIGINAL ARTICLE

Relationship between patient-based scoring systems and the activity level of patients measured by wearable activity trackers in lumbar spine disease

Masahiro Inoue[1] · Sumihisa Orita[1] · Kazuhide Inage[1] · Miyako Suzuki[1] · Kazuki Fujimoto[2] · Yasuhiro Shiga[1] · Hirohito Kanamoto[3] · Koki Abe[1] · Hideyuki Kinoshita[4] · Masaki Norimoto[1] · Tomotaka Umimura[1] · Takashi Sato[1] · Masashi Sato[1] · Masahiro Suzuki[1] · Keigo Enomoto[1] · Yawara Eguchi[5] · Yasuchika Aoki[6] · Tsutomu Akazawa[7] · Yohei Kawasaki[8] · Seiji Ohtori[1]

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Abstract

Purposes To evaluate whether a relationship exists between patient-based scoring systems and the activity level of patients with low back pain (LBP) by using wearable activity trackers, and to determine whether activity level was affected by patient factors.

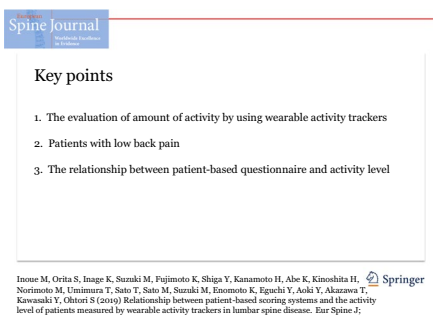
Methods The subjects were 66 patients with LBP. The physical activity of participants was objectively evaluated using the Micro-Motion logger (Actigraph). The activity level was analyzed with the mean active count of the proportional-integrating mode (PMAC) and zero-crossing mode. Clinical symptoms were evaluated using the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire (JOABPEQ), Roland–Morris Disability Questionnaire, the Oswestry Disability Index, and visual analog scale (VAS). The relationships between each item of the patient-based questionnaire and activity level, and the influence of individual factors (age, sex, body mass index [BMI], low back pain, and muscle mass) on the activity level were evaluated.

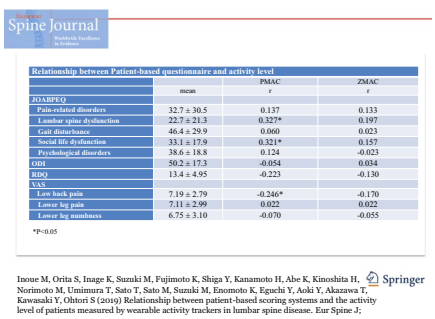
Results In each domain of the JOABPEQ, lumbar spine dysfunction and social life dysfunction were correlated with PMAC ($r = 0.327$ and 0.321, respectively). The low back pain VAS scores were correlated with PMAC ($r = -0.246$). Multiple regression analysis shows that individual factors affecting the activity level of patients with LBP were sex, BMI, low back pain, and muscle mass in PMAC ($p < 0.01$).

Conclusions Some domains of the questionnaires were correlated with activity level, but others were not. Additionally, the activity level of patients with LBP was affected by sex, BMI, LBP, and skeletal muscle mass index.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.





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Keywords Wearable activity tracker · Quality of life · Patient-based questionnaire · Lumbar spine disease · Low back pain

Introduction

Low back pain is one of the most common causes of physical complaints; therefore, it is important to understand its pathology to increase the quality of life and reduce medical expenses in the aging society [1]. The primary goal for patients with low back pain is the recovery of ambulation and rapid return to routine activity by undergoing appropriate treatments, such as medication, rehabilitation, and spine surgery. However, the level of difficulty these patients encounter because of their inability to perform activities of daily living remains unknown. Patient-based scoring systems, such as the Roland–Morris Disability Questionnaire (RDQ), the Oswestry Disability Index (ODI), and the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire (JOABPEQ), are used to evaluate pathology and therapeutic effects associated with low back pain [2–5]. However, it is difficult to gather and analyze objective data regarding how patients' back pain affects their everyday lives or how effective treatments are. Furthermore, one limitation of these systems is that they are patient oriented: We cannot tell how well they reflect the patients' real activities. As a solution to this problem, the use of wearable sensors to capture an individual's movements and physical activity has attracted attention with respect to health outcome measurements [6]. For instance, sleep activity and efficiency, which are reportedly related to cumulative body movements, and movement-related acceleration (which in turn correlates with energy consumption) were monitored using accelerometers [7, 8]. These devices collect and store measurements related to patients' daily living behavior, such as exercise, sleeping habits, and changes in vital signs. Recent developments in modern technology have enabled wearable accelerometers to be integrated into wrist and waistbands for easy-to-use monitoring of daily activities; yet, very few studies have reported the real-time activity of patients with low back pain [9]. Smuck et al. [10] reported a discrepancy between the change in a patient-based outcome score and the change in the amount of activity before and after lumbar decompression surgery. Although low activity levels were expected in patients with low back pain, the patient factors that contribute to the amount of activity are unknown.

The purposes of the current study were to measure the activity level of patients with low back pain by using wearable activity trackers and to evaluate whether patient-based scoring systems and amount of activity were related. In addition, we evaluated whether the activity level of patients was affected by patient factors such as pain and muscle volume.

Materials and methods

Participants and ethical considerations

The participants were patients with chronic low back pain who were admitted to our hospital for degenerative lumbar spine disease from November 2016 to April 2018. The inclusion criteria were as follows: (1) age between 30 and 90 years; (2) predominant low back pain lasting more than 3 months; and (3) degenerative lumbar spine disease confirmed on magnetic resonance imaging. The exclusion criteria were as follows: (1) use of an aid for walking; (2) presence of motor deficit; (3) presence of painful osteoarthropathy; (4) coexisting gait disorder associated with a disease other than degenerative lumbar spine disease; and (5) a psychiatric or cognitive disorder. The study was approved by the ethics committee of our institution. All participants were informed of the purpose of the study, received information, and provided written consent.

Physical activity measures

The objective physical activity of participants was evaluated using the Actigraph Micro-Motion logger (Ambulatory Monitors Inc., Ardsley, NY, USA), a waterproof omnidirectional accelerometer (size: 2.5 × 0.9 cm; weight: 14 g). The device uses a piezoelectric element, with which acceleration is transduced with a sensitivity of 0.01 G/min; these voltages were recorded and averaged in 1-minute epochs. The Actigraph is an evidence-based tracking system designed for continuous 24-hour monitoring and analysis of activity levels and movement counts during both waking and sleep hours. Each participant wore the logger on the non-dominant wrist for 1 week, 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 validated algorithms (the Cole–Kripke, Sadeh, and University of California, San Diego) [11]. Our main outcome measure was the mean active count (MAC) measured in two different modes described below; these items have been reported in previous studies, enabling us to make comparisons with our results [11–15]. The two modes used were (1) the zero-crossing mode (ZCM), indicating the number of movements in a 1-min epoch, and (2) the proportional-integrating mode (PIM), indicating the total amount of movement in a 1-minute epoch. For ZCM, the signal voltage from the accelerometer is compared to the reference voltage, with each zero-crossing generating an activity count (range 0–255). 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.

Patient-based questionnaires

Clinical symptoms were evaluated using the visual analog scale (VAS) score for low back pain, leg pain, and leg numbness (scores range from 0 mm [no pain] to 100 mm [extreme pain]); the ODI (0–100 points); the RDQ (0–24 points); and the JOABPEQ. The first two items, VAS and ODI, can be used to evaluate lumbar pain, leg pain, and numbness, but they 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 quality of life (QOL). The JOABPEQ includes 25 questions based on the RDQs and Short Form 36 (SF-36). The 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 published guidelines and ranges from 0 to 100 points. Lower scores indicate greater symptom severity, which is deemed proportional to the patient's clinical condition [16, 17]. All questionnaires were administered during the week that the patients wore the activity trackers.

Muscle volume measurements

Dual-energy X-ray absorptiometry (DXA) scan (Discovery; Hologic, Waltham, MA, USA) was used for body composition analysis. DXA provides bone density estimates and regional estimates of body composition (i.e., parts of the body) by measuring the body's absorbance of X-rays at two different energies. This technology uses the fact that fat, bone mineral, and fat-free soft tissue have different absorption properties. Subjects underwent DXA to obtain arm and leg muscle masses (kg) [18]. Appendicular muscle mass (kg) was calculated as the sum of the muscle mass of the arms and legs. The skeletal muscle mass index (SMI) was calculated using the following formula:

SMI (kg/m^2) = appendicular muscle mass (kg)/body height^2 (m^2) [19].

Statistical analysis

To evaluate whether there was an association between physical activity and patient-based questionnaire scores, simple correlations between each questionnaire score and MAC in ZCM (ZMAC) and PIM (PMAC) were obtained through Pearson's linear correlation coefficient.

To identify individual factors that are associated with physical activity in patients with low back pain, the influence of individual factors on the activity level was evaluated using multiple regression analysis. The physical activity level was used as the dependent variable. Moreover, age, sex, body mass index (BMI), SMI, and low back pain VAS score were used as independent variables. Statistical significance was set at a p value of < 0.05. All statistical procedures were performed using SAS 9.4 for Windows (SAS Institute Inc., Cary, NC, USA). All data are reported as means ± standard deviations, unless otherwise indicated.

Results

The current study included 66 patients, 35 men and 31 women. The mean age was 69.8 ± 9.5 years (minimum [min] 37, maximum [max] 88). The mean BMI was 24.2 ± 4.2 kg/m^2. The mean duration of morbidity was 48.83 ± 49.73 months (min 2, max 180). The disease breakdown included 45 cases of lumbar spinal stenosis, 13 cases of lumbar spondylolisthesis, six cases of degenerative lumbar scoliosis, and two cases of lumbar degenerative disk disease (Table 1).

Relationship between the patient-based questionnaire scores and activity level

Table 2 depicts the relationships between the patient-based questionnaire scores and activity levels. In each domain of the JOABPEQ, lumbar spine dysfunction and social life dysfunction were correlated with the proportional-integrating active count (PMAC) ($r = 0.327$, 0.321, respectively; $p < 0.05$). However, there was no correlation among the other domains. Neither ODI nor RDQ was correlated with PMAC. The low back pain VAS scores were correlated with PMAC ($r = -0.246$; $p < 0.05$), but there were no correlations between the lower extremity pain VAS score, the lower extremity numbness VAS score, and activity level. On the other hand, there were no correlations between patient-based questionnaire scores and ZMAC.

Table 1 Demographic data

No. of patients	66
Age, mean (range), years	69.8 ± 9.5 (37–88)
Sex (male/female)	35/31
Body mass index (kg/m^2)	24.2 ± 4.2
Duration of morbidity (range), months	48.8 ± 49.7 (2–180)
Diagnosis	
Lumbar spinal stenosis	45 (68%)
Lumbar spondylolisthesis	13 (20%)
Degenerative lumbar scoliosis	6 (9%)
Lumbar degenerative disk disease	2 (3%)

Table 2 Relationship between the patient-based questionnaire and activity level

	Mean	PMAC	ZMAC
		R	*R*
JOABPEQ			
Pain-related disorders	32.7 ± 30.5	0.137	0.133
Lumbar spine dysfunction	22.7 ± 21.3	0.327*	0.197
Gait disturbance	46.4 ± 29.9	0.060	0.023
Social life dysfunction	33.1 ± 17.9	0.321*	0.157
Psychological disorders	38.6 ± 18.8	0.124	− 0.023
ODI	50.2 ± 17.3	− 0.054	0.034
RDQ	13.4 ± 4.95	− 0.223	− 0.130
VAS			
Low back pain	7.19 ± 2.79	− 0.246*	− 0.170
Lower leg pain	7.11 ± 2.99	0.022	0.022
Lower leg numbness	6.75 ± 3.10	− 0.070	− 0.055

*$p<0.05$

JOABPEQ Japanese Orthopaedic Association Back Pain Evaluation Questionnaire, *ODI* Oswestry Disability Index, *RDQ* Roland–Morris Disability Questionnaire, *VAS* visual analog scale, *PMAC* mean active count in the proportional-integrating mode, *ZMAC* mean active count in the zero-crossing mode

Table 3 Multiple linear regression analysis of the individual factors in ZMAC

Independent variables	Regression coefficient	95% CI	*P* value	R^2
			0.004*	0.256
Intercept	0		0.009	
Sex (male)	− 0.570	− 0.902; − 0.234	0.001	
Age	0.163	− 0.070; 0.395	0.168	
Low back pain	− 0.154	− 0.400; 0.093	0.217	
BMI	− 0.598	− 0.971; − 0.198	0.004	
SMI	0.691	0.220; 1.132	0.004	

*Analysis of variance of this model

ZMAC mean active count in the zero-crossing mode, *BMI* body mass index, *SMI* skeletal mass index, *CI* confidence interval

Relationship between patient factors and activity level

Multivariate analyses of the relationships between individual factors, ZMAC, and PMAC are shown in Tables 3 and 4. In multiple regression analysis, ZMAC was negatively correlated with sex and BMI (activity decreased with male sex and increased with BMI) and positively correlated with SMI (activity increased with higher muscle mass). PMAC was also associated with sex, BMI, SMI, and low back pain in that the amount of activity decreased with the progression of low back pain. For both PMAC and ZMAC, BMI and SMI had a strong influence on activity level. Forest graphs were prepared by using the standardized regression coefficient of the model and the 95% confidence interval for the above results (Figs. 1 and 2).

Discussion

In the current study, the activities of daily living of patients with low back pain were objectively evaluated using a wearable activity tracker, Actigraph. Between patient-based outcomes and activity levels, the lumbar spine dysfunction and social life dysfunction domains of the JOABPEQ correlated with PMAC. However, ODI and RDQ scores and Actigraph data were not correlated. Additionally, individual factors affecting the activity level of patients with low back pain were sex, BMI, low back pain, and SMI in PMAC, and sex, BMI, and SMI in ZMAC.

Few studies have compared activity between healthy people and patients with low back pain using a wrist-watch-type accelerometer. In previous studies, amounts of trunk movements were significantly lower in patients with low back pain than in healthy controls [20]. Moreover, Liszka-Hackzell et al. and Hashimoto et al. [21, 22] reported a significant correlation between the intensity of low back pain and activity level, and a similar result was found herein. The domains

Table 4 Multiple linear regression analysis of individual factors in PMAC

Independent variables	Regression coefficient	95% CI	*P* value	R^2
			0.005*	0.250
Intercept	0.017		0.006	
Sex (male)	− 0.543	− 0.870; − 0.204	0.002	
Age	− 0.160	− 0.390; 0.073	0.176	
Low back pain VAS	− 0.258	− 0.501; − 0.009	0.042	
BMI	− 0.640	− 1.006; − 0.236	0.002	
SMI	0.719	0.243; 1.151	0.003	

*Analysis of variance of this model

PMAC mean active count in the proportional-integrating mode, *BMI* body mass index, *SMI* skeletal mass index, *CI* confidence interval

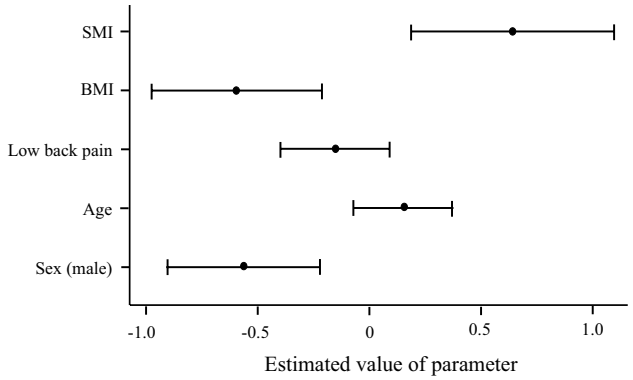

Fig. 1 Estimated value of the standardized regression coefficient of each item in ZMAC. The width of each graph shows the 95% confidence interval, and the point indicates the regression coefficient. ZMAC, the mean active count of zero-crossing mode; SMI, skeletal mass index; BMI, body mass index

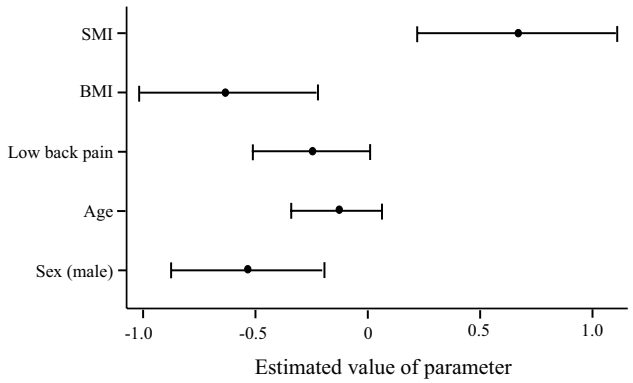

Fig. 2 Estimated value of the standardized regression coefficient of each item in PMAC. The width of each graph shows the 95% confidence interval, and the point indicates the regression coefficient. PMAC, the mean active count of proportional-integrating mode; SMI, skeletal mass index; BMI, body mass index

of lumbar spine dysfunction and social life dysfunction in the JOABPEQ correlated with the activity level. No study has shown the relationship between actual physical activity and each domain. However, in our study, we considered that lumbar spine dysfunction was affected by lower trunk movements in patients with low back pain, and social life dysfunction may be influenced by lifestyle and sex. Regarding the other questionnaire, Chiarotto et al. [23] reported that the RDQ had better construct validity as a measure of physical functioning than the ODI. However, in the current study, the RDQ score was not related to measured activity levels. Moreover, the relationships between gait disturbance, psychological disorders, lower limb pain, and lower limb numbness, which seemed to be related to walking and the activity level, were poor, and a dissociation was identified between these patient-based outcomes and the measured value. Thus, it seemed that the patient-based questionnaires did not perform well when used as tools to evaluate the activity level. Although the current patient-based outcome questionnaire method is useful for evaluating subjective parameters such as pain and patient satisfaction, it is not accurate for objectively evaluating the level of activity.

The level of activity primarily depends on individual life habits and professional status. Therefore, the correlation between activity level and low back pain will be essentially dependent of the usual level of activity of the patient, before the occurrence of the low back pain episode. It is therefore expected that the amount of activity will decrease with age, but in our study, no difference in age was found. The current study measured the activity level among patients with low back pain irrespective of patient age, so it is possible that there could have been some level of movement restriction even in relatively young people. Yet, regardless of age, physical activity, sex, BMI, SMI, and low back pain were related.

Visser et al. [24] reported that lower muscle mass and greater fat infiltration into the muscle are associated with an increased risk of loss of mobility. On the other hand, Mikkola et al. [25] reported that physical performance correlated with fat mass better than lean mass. In the evaluation of body composition, activity level was related to SMI. Although we were not able to evaluate the relationship with fat mass specifically in our study, the decrease in activity levels with increasing BMI suggests that body weight gain and increased fat mass correlate with decreased activity levels. In addition, our results suggest that decreased muscle mass and increased body weight as well as low back pain may cause decreased activity levels.

The current study has some limitations. First, there is no control group of healthy individuals. Even healthy people are influenced regarding the amount of activity in their lifestyle. Therefore, our results are not essentially specific to patients with back pain. Second, radiography was used to evaluate patients' composition, but it could not be performed for healthy people for ethical and cost-related reasons. Thus, it is necessary to compare composition between patients with back pain and healthy people in the future. Third, since the current study included only patients with lumbar spine disease, the effects of long-term morbidity related to disuse, symptom intensity, previous treatment regimens, and disease-specific effects cannot be excluded. Involvement of the disease itself in the activity level needs to be studied in the future. Moreover, our study did not include questionnaires that reflect medical economics, such as the EQ-5D and SF-36, which should be included in future studies.

Treatment for low back pain is necessary to improve patients' QOL and productivity. Although subjective evaluation using a patient-based questionnaire, which is the conventional evaluation method, is important, accurate evaluation of the activity level over time is difficult. In contrast, performing an objective assessment using the wearable

trackers before and after treatment would allow changes in patients' QOL to be measured. This seems to be very useful considering the cost-effectiveness of wearable trackers in combination with treatment such as surgery. The use of an activity tracker should be an integral part of the pre-treatment and post-treatment assessments of low back pain, and a combination of the subjective evaluation and activity evaluation with the wearable activity tracker will make more practical evaluation of the QOL possible.

Conclusions

We objectively evaluated activity levels in the daily life of patients with lumbar spine disease by using wearable trackers. We found that lumbar spine dysfunction and social life dysfunction domains of the JOABPEQ were correlated with activity level in patient-based outcomes. However, dissociation between the activity level and patient-based outcomes was seen in specific cases. Additionally, individual factors affecting the activity level of patients with low back pain were sex, BMI, low back pain, and SMI.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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Affiliations

Masahiro Inoue[1] · Sumihisa Orita[1] · Kazuhide Inage[1] · Miyako Suzuki[1] · Kazuki Fujimoto[2] · Yasuhiro Shiga[1] · Hirohito Kanamoto[3] · Koki Abe[1] · Hideyuki Kinoshita[4] · Masaki Norimoto[1] · Tomotaka Umimura[1] · Takashi Sato[1] · Masashi Sato[1] · Masahiro Suzuki[1] · Keigo Enomoto[1] · Yawara Eguchi[5] · Yasuchika Aoki[6] · Tsutomu Akazawa[7] · Yohei Kawasaki[8] · Seiji Ohtori[1]

✉ Masahiro Inoue
masain_96@hotmail.com

[1] Department of Orthopaedic Surgery, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan

[2] Department of Orthopaedic Surgery, Saiseikai Narashino Hospital, 1-1-1 Izumi-cho, Narashino City, Chiba 275-8580, Japan

[3] Department of Orthopaedic Surgery, Kanamoto Orthopaedics Clinic, 740-7 Matunaga, Numazu City, Shizuoka 410-0874, Japan

[4] Department of Orthopaedic Surgery, Shimoshizu National Hospital, 934-5 Kawatari, Yotsukaido City, Chiba 284-0003, Japan

[5] Department of Orthopaedic Surgery, Chiba Cancer Center, 666-2 Nitona-cho, Chuo-ku, Chiba 260-0801, Japan

[6] Department of Orthopaedic Surgery, Eastern Chiba Medical Center, 3-6-2 Okayamadai, Togane City, Chiba 283-8686, Japan

[7] Department of Orthopaedic Surgery, St. Marianna University School of Medicine, 2-16-1 Sugao, Miyamae-ku, Kawasaki, Kanagawa 216-8511, Japan

[8] Biostatistics Section, Clinical Research Center, Chiba University Hospital, 1-8-1 Inohana, Chuo-ku, Chiba 260-8677, Japan