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Original Article

Gait cycle time variability in patients with knee osteoarthritis and its possible associating factors

Takeshi Akimoto, RPT, MS[1, 2)*], Kenji Kawamura, MD[1)], Takaaki Wada, RPT[2)], Naomichi Ishihara, RPT[2)], Akane Yokota, RPT[2)], Takehiko Suginoshita, MD[2)], Shigeki Yokoyama, RPT, PhD[3)]

[1)] Graduate School of Health Science, Kibi International University: 8 Iga-cho, Takahashi-shi, Okayama 716-8508, Japan
[2)] Department of Orthopedics, Medical Corporation Suginoshita Orthopedic Clinic, Japan
[3)] Graduate School of Health Science, Kyoto Tachibana University, Japan

Abstract. [Purpose] Knee osteoarthritis can alter gait variability; however, few studies have investigated the associating factors with gait cycle time variability. The first objective was to compare gait cycle variability between female patients with knee osteoarthritis and healthy elderly females and to determine gait characteristics in patients with knee osteoarthritis. The second objective was to identify the associating factors with gait cycle time variability. [Participants and Methods] The participants included 24 female patients diagnosed with knee osteoarthritis and 12 healthy elderly females. Gait cycle variability (coefficient of variation of gait cycle time), knee extension range of motion, knee extension strength, 5-m walk test, Timed Up & Go Test, and Western Ontario and McMaster Universities Osteoarthritis Index were measured. All assessment results were compared between the knee osteoarthritis and healthy groups. [Results] Gait cycle time variability was significantly higher in the knee osteoarthritis group than in the healthy group. Further, it showed a significant positive correlation with the 5-m walk test and the Western Ontario and McMaster Universities Osteoarthritis Index. [Conclusion] Patients with knee osteoarthritis presented greater gait cycle variability than that of healthy individuals. Therefore, rehabilitation to improve gait variability might enhance the quality of life of patients with knee osteoarthritis.

Key words: Knee osteoarthritis, Gait cycle variability, Gait speed

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INTRODUCTION

Knee osteoarthritis (OA) is a common disease that imposes an enormous personal and social burden. In Japan, Yoshimura et al.[1)] reported that the prevalence of radiographic knee OA was 42.6% in males and 62.4% in females aged >40 years, indicating that knee OA is an epidemiologically important disease. Knee OA is a common disease in elderly females[2)] and is a leading cause of pain and dysfunction[3)]. The main symptom is decreased gait ability, which can negatively impact activities of daily living and quality of life (QOL)[4)]. Therefore, it is vital to accurately assess the gait ability of patients with knee OA and to improve it through rehabilitation.

It has been widely reported that knee OA diminishes gait function. Additionally, spatiotemporal gait parameters, such as slower gait speed, shorter stride length, increased stride time, increased stance phase duration, and increased double support time, are worsened[5–8)]. Knee OA has recently been shown to alter gait variability, which provides important information about the rhythmic pattern of the gait cycle. Aging and various pathological conditions can alter neuromusculoskeletal behavior and disrupt the rhythm of the gait cycle. For example, previous studies have shown that gait variability was greater in community-dwelling older adults with a history of falls[9–11)].

*Corresponding author. Takeshi Akimoto (E-mail: suginoshita.c.akimoto@gmail.com)

Research on gait variability in patients with knee OA is ongoing. Gait variability has been compared between patients with knee OA and healthy individuals and among patients with different Kellgren–Lawrence severity levels and outcomes have differed in each study[12–16]. In particular, studies focusing on the variability of spatiotemporal parameters have investigated the standard deviation and coefficient of variation (CV) of gait cycle time and stance time. Clermont et al. and Tanimoto et al.[12, 13] reported no significant difference in the gait cycle time standard deviation or CV between the knee OA and healthy groups. However, Kiss[14] reported that the knee OA group had a significantly higher CV of stance time. Oka et al.[15] reported a significant difference in the gait cycle time CV between patients with knee OA with a fear of falling and those without a fear of falling. Thus, many studies have been reported focusing on the gait variability of spatiotemporal parameters of knee OA. The gait variability of knee OA may be greater than that of healthy individuals.

To the best of our knowledge, no study has so far investigated associating factors with gait cycle variability (knee joint functions, such as muscle strength and range of motion, and physical functions, such as gait speed). Examining the associating factors with gait cycle variability in knee OA is important information for improving gait variability. Many researchers have investigated gait variability in healthy older adults. Hausdorff et al.[9] and Balasubramanian et al.[17] reported that gait variability is related to gait speed in community-dwelling older adults. In addition, Bogen et al.[18] reported that gait variability tended to be related to muscle strength measured two years earlier. Matsuda et al.[19] suggested that muscle strength must be improved to reduce gait variability. Thus, studies have investigated associating factors with gait cycle variability among older adults in the community. We expect that there are associating factors with gait variability in patients with knee OA as well as in healthy individuals.

The first objective of this study was to compare gait cycle variability between female patients with knee OA and healthy elderly females and to determine gait characteristics in patients with knee OA. The second objective was to identify associating factors with gait cycle variability in knee OA. We hypothesized that 1) gait cycle variability would be greater in knee OA than in healthy participants and 2) potential factors, such as muscle strength, would be associated with gait cycle variability.

PARTICIPANTS AND METHODS

This study recruited participants in two groups: patients with knee OA and healthy elderly females. Twenty-four female patients diagnosed with knee OA by radiography were included in the knee OA group, and 12 healthy age-matched females living in the community were included in the healthy group. The Kibi International University Ethics Committee approved all measures of this study (approval number: 19-14). All participants provided written informed consent before participating in the study.

The criteria for inclusion in the knee OA group were (1) females and (2) patients who could participate in rehabilitation at least once a week. The exclusion criteria were (1) severe pain other than knee pain, (2) history of lower extremity trauma or surgery, (3) history of severe cardiac or pulmonary disease, and (4) history of rheumatoid arthritis. The inclusion criterion for the healthy group was (1) females. The exclusion criteria were (1) pain in the lower limbs, (2) a history of lower extremity trauma or surgery, (3) a history of severe cardiac or pulmonary disease, and (4) a history of rheumatoid arthritis. The Kellgren–Lawrence classification of the knee OA group was grade I (no patient), grade II (15 patients), grade III (8 patients), and grade IV (1 patient).

Before the trial task, participants were given practice time to become accustomed to gait on the treadmill. The speed of the gait practice started at 0.8 km/h, and the examiner increased the speed by 0.1 km/h while checking the condition of the participants. The comfortable gait speed was determined during the gait practice. The participants were asked to inform the examiner when they had reached "the speed at which they normally gait". This speed was determined as the comfortable gait speed for each participant. This comfortable gait speed was used for data collection in this study. After an adequate rest period, the participants walked on the treadmill for 1 min at a comfortable gait speed (comfortable speed was 2.3 ± 0.8 km/h for the knee OA group and 2.5 ± 0.8 km/h for the healthy group). During the task, the rating of the perceived exertion scale (Borg's 6–20 scale) was assessed to investigate exercise intensity[20].

A triaxial accelerometer (TSND121, ATR-Promotions Co., Kyoto, Japan) was used to collect data during the trial. The size of the sensor was 37 mm×46 mm×12 mm and weighed 22 g. A triaxial accelerometer was attached to the third lumbar vertebra of each participant. The acceleration waveform data during gait were transmitted to the computer via Bluetooth. The raw sensor data were sampled at a frequency of 100 Hz. The gait cycle time CV was measured by referring to the method of Inoue et al[21]. The heel ground contact of the gait was analyzed from the pattern of peak acceleration[12]. The duration of one gait cycle was defined as the time between heel ground contact and the next heel ground contact on the same side. The CV, which is the ratio of the standard deviation to the mean, was calculated from the obtained gait cycle time. This CV was defined as the gait cycle variability and was used in the results.

Knee extension range of motion (ROM) and knee extension strength were measured to evaluate knee joint function. Knee extension ROM was measured in the supine position using a goniometer. A hand-held dynamometer (μTas F-1, Anima Co., Tokyo, Japan) was used to measure knee extension strength. Knee extension strength was measured as the isometric strength at 90° of knee flexion. The dynamometer was restrained with a belt to improve the reliability of isometric muscle strength measurement[22].

The 5-m walk test (5MWT)[23] and Timed Up & Go Test (TUG)[24] were used to assess gait ability. The 5MWT measured the gait speed over a distance of 5 m. An 11-m gait path was used, with 3 m at each end prepared for acceleration and deceleration and the central 5 m used for measurement. The participants were instructed to walk as quickly as possible. The TUG measured the time it took for a participant to get up from a chair, to walk 3 m, to turn around, to walk back to the chair, and to sit down. Moreover, the participants were instructed to walk as quickly as possible during the TUG measurement. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[25] was used to assess pain, stiffness, and function. The WOMAC was used as a specific QOL measure for knee OA. Higher WOMAC scores indicate more severe functional limitations.

The statistical software IBM SPSS for Windows (version 26, IBM Corp., Armonk, NY, USA) was used for the statistical analysis. Physical characteristics, gait cycle variability, gait speed on the treadmill, Borg's 6–20 scale, knee extension strength, knee extension ROM, 5MWT, TUG, and WOMAC were compared between the knee OA and healthy groups. Normality was checked using the Shapiro–Wilk test, and either the t-test or Mann–Whitney U test was performed. The effect size r was calculated from the T-value (for t-test) and Z-value (for Mann–Whitney U test) using Microsoft Excel.

In addition, the relationships between gait cycle variability and knee extension strength, knee extension ROM, 5MWT, TUG, and WOMAC in the knee OA group were examined. Normality was checked using the Shapiro–Wilk test, and Spearman's rank correlation coefficient was used. Correlation results were interpreted as negligible ($p<0.30$), weak ($p=0.30$–0.50), moderate ($p=0.50$–0.70), high ($p=0.70$–0.90), or very high ($p>0.90$).

The sample size was determined after conducting a pilot study with 12 participants (6 in the OA group and 6 in the healthy group). The gait cycle time variability was used as the variable for sample size determination. The allocation ratio was 2:1 for the knee OA and healthy groups, and the significance (α) and power were set at 0.05 and 0.8, respectively. The calculated sample size was 20 for the OA group and 10 for the healthy group, and we were able to recruit a sufficient number of participants.

RESULTS

The participants' characteristics for the knee OA and healthy groups are shown in Table 1. There were no significant differences in age, height, weight, or BMI between the knee OA and healthy groups.

Gait cycle variability was significantly higher in the knee OA group than in the healthy group (medium effect size, 0.44). The comfortable gait speed on the treadmill was not significantly different between the knee OA group and the healthy group. The Borg's 6–20 scale during the gait task corresponded to "fairly light" in both groups, with no significant difference (Table 2). The results of the other measurements are presented in Table 2.

Knee function was significantly lower in the knee OA group in terms of both extensor muscle strength and extension ROM (medium to large effect size, 0.41–0.52). The 5MWT and TUG results were significantly slower in the knee OA group (medium to large effect size, 0.43–0.55). The WOMAC scores were significantly higher in the knee OA group (large effect size, 0.69).

Furthermore, Table 3 shows the results of the correlations between gait cycle variability and knee extension strength, knee extension ROM, 5MWT, TUG, and WOMAC in the knee OA group. A significant weak positive correlation was found between gait cycle variability and 5MWT. In addition, there was a significant weak positive correlation between gait cycle variability and WOMAC scores. There was no significant association between gait cycle variability and other factors (Table 3).

Table 1. Participant characteristics

	Knee OA group (n=24)	Healthy group (n=12)
Age (years)	70.8 ± 5.7	69.8 ± 8.1
Height (cm)	155.9 ± 5.1	153.0 ± 6.1
Body mass (kg)	56.6 ± 6.4	53.5 ± 6.1
BMI (kg/m^2)	23.3 ± 2.4	22.9 ± 2.9
KL Score (n)		
Grade I	0	
Grade II	15	
Grade III	8	
Grade IV	1	

Data are presented as mean ± SD (standard deviation). OA: osteoarthritis; BMI: body mass index; KL: Kellgren-Lawrence.

Table 2. Comparison of gait on the treadmill, knee function, gait ability, and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) between the knee osteoarthritis (OA) group and healthy group

	Knee OA group (n=24)	Healthy group (n=12)	p-value	Effect size r
Gait on the treadmill				
Gait cycle variability (%)	3.2 ± 1.5	2.1 ± 0.7	**	0.44
Gait speed on the treadmill (km/h)	2.3 ± 0.8	2.5 ± 0.8		0.10
Borg's 6–20 scale	11.0 ± 2.3	11.1 ± 1.3		0.01
Knee function				
Knee extension ROM (°)	−4.2 ± 4.3	−0.8 ± 1.9	*	0.41
Knee extension strength (kgf/kg)	0.38 ± 0.09	0.51 ± 0.12	***	0.52
Gait ability				
5MWT (s)	3.8 ± 0.9	2.9 ± 0.3	***	0.55
TUG (s)	6.8 ± 1.0	5.9 ± 0.4	**	0.43
Assessments of pain, stiffness, and function				
WOMAC	20.5 ± 9.0	4.3 ± 7.4	***	0.69

Data are presented as mean ± SD (standard deviation). OA: osteoarthritis; ROM: range of motion; 5MWT: 5-meter walk test; TUG: Timed Up & Go test; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

Table 3. Potential contributing factors associated with gait cycle variability in the knee osteoarthritis (OA) group

	Knee OA group (n=24)	
	Spearman's rank correlation coefficient (ρ)	p-value
Knee extension ROM	−0.25	
Knee extension strength	−0.24	
5MWT	0.46	*
TUG	0.33	
WOMAC	0.43	*

OA: osteoarthritis; ROM: range of motion; 5MWT: 5-meter walk test; TUG: Timed Up & Go test; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

DISCUSSION

This study investigated whether gait cycle variability differed between the knee OA and healthy groups. There were no significant differences in age, height, weight, or BMI between the knee OA and healthy groups (Table 1). In other words, there was no difference in the physical characteristics between the two groups, and the knee OA group alone had OA symptoms, such as knee pain. Therefore, the participants in this study were suited to the purpose of the study, which was to compare patients with knee OA with healthy individuals.

The results showed that the gait cycle variability of the knee OA group was significantly larger than that of the healthy group, indicating that gait cycle variability might play an important role in the rehabilitation of patients with knee OA.

Borg's 6–20 scale for treadmill gait showed no significant difference between the two groups (Table 2). Therefore, the gait task speed was appropriate in terms of exercise intensity because participants in both groups fell into the "fairly light" category and performed the task at the same intensity.

Gait cycle variability was significantly greater in the knee OA group than in the healthy group. Kiss[14)] reported a significantly greater stance time CV in the knee OA group than in the healthy group. Therefore, among the studies comparing the CV of spatiotemporal gait parameters, the present study supports the work of Kiss[14)]. Kiss[14)] used the same gait speed for all participants when collecting data on treadmill gait. On the other hand, the present study collected data at a comfortable gait speed for each participant. A new finding was that the gait variability of spatiotemporal parameters in the knee OA group was greater than that in the healthy group, even at the participants' daily gait speed. Furthermore, previous studies have reported that increased gait variability is associated with an increased risk of falls[9–11)]. Although our study did not investigate falls, the gait of patients with knee OA may be associated with a higher risk of falling than that of healthy individuals.

Knee joint function, gait speed, and the WOMAC scores were lower in the knee OA group than in the healthy group (Table 2). Previous studies have also reported reduced knee extensor strength and gait speed in patients with knee OA compared with those in healthy individuals[6–8, 26, 27)], which means that the present study results support those of previous studies. Furthermore, there were significant weak positive correlations between gait cycle variability and 5MWT (r=0.46) and between gait cycle variability and WOMAC (r=0.43). Gait cycle variability has been reported to correlate with gait speed in healthy participants[9, 17]. The present study showed that gait cycle variability was associated with gait speed, even in patients with knee OA. It has been suggested that WOMAC is a reliable and valid measure of QOL in patients with OA[28]. Therefore, the correlation of gait cycle variability with WOMAC indicates that gait variability reflects the QOL and physical function in patients with knee OA. Kalsi-Ryan et al.[29] reported a correlation between Japan Orthopedic Association score and gait CV in patients with spondylolisthesis osteoarthritis. Correlation with such disease-specific assessments of physical functioning, even in patients with knee OA, indicates that gait variability is associated with QOL. Therefore, reducing gait CV may lead to improved QOL.

On the other hand, no relationship was found between knee function and gait cycle variability. This result differs from our hypothesis. It has been reported that there is an association between gait cycle variability and knee extension strength in healthy older adults[9, 18, 19]. There was a difference in the results for knee OA. To the best of our knowledge, no previous study has examined the relationship between gait cycle variability and extensor muscle strength in knee OA. Therefore, different factors may be associated with gait cycle variability in patients with knee OA than in healthy older adults. A previous study on local older adults reported a correlation between hip abduction strength and gait cycle variability[19]. In this study, knee extension strength alone was evaluated; therefore, it is necessary to evaluate knee flexion strength and hip joint strength in the future.

This study has some limitations. First, the study included 24 participants in the knee OA group and 12 in the healthy group, which is a small sample size. The sample size may have affected the results. Second, the trial task was gait on a treadmill. Although the participants were given time to practice, it is possible that their experience with the treadmill may have influenced the results. One of the reasons for adopting the treadmill gait was to increase the number of steps. Lord et al.[30] reported that it is possible to measure gait cycle variability even at 10 m walking, although in many cases, a certain number of steps is ensured, such as measuring 100 gait cycles or 6–10 min of walking[31, 32]. Therefore, we adopted the treadmill gait to increase the number of steps. However, treadmill gait has a disadvantage, in that it is different from a normal gait. In the future, it will be necessary to consider the study's design to increase the number of steps with a continuous gait in a large space.

In conclusion, the gait of patients with knee OA showed greater gait variability than that of healthy individuals. In addition, gait variability may be associated with gait speed and QOL. Therefore, rehabilitation to improve gait variability may enhance the QOL of patients with knee OA.

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REFERENCES

1) Yoshimura N, Muraki S, Oka H, et al.: Prevalence of knee osteoarthritis, lumbar spondylosis, and osteoporosis in Japanese men and women: the research on osteoarthritis/osteoporosis against disability study. J Bone Miner Metab, 2009, 27: 620–628. [Medline] [CrossRef]
2) Garriga C, Sánchez-Santos MT, Judge A, et al.: Predicting incident radiographic knee osteoarthritis in middle-aged women within four years: the importance of knee-level prognostic factors. Arthritis Care Res (Hoboken), 2020, 72: 88–97. [Medline] [CrossRef]
3) Murphy SL, Schepens Niemiec S, Lyden AK, et al.: Pain, fatigue, and physical activity in osteoarthritis: the moderating effects of pain- and fatigue-related activity interference. Arch Phys Med Rehabil, 2016, 97: S201–S209. [Medline] [CrossRef]
4) Choojaturo S, Sindhu S, Utriyaprasit K, et al.: Factors associated with access to health services and quality of life in knee osteoarthritis patients: a multilevel cross-sectional study. BMC Health Serv Res, 2019, 19: 688. [Medline] [CrossRef]
5) Mills K, Hunt MA, Ferber R: Biomechanical deviations during level walking associated with knee osteoarthritis: a systematic review and meta-analysis. Arthritis Care Res (Hoboken), 2013, 65: 1643–1665. [Medline]
6) Sparkes V, Whatling GM, Biggs P, et al.: Comparison of gait, functional activities, and patient-reported outcome measures in patients with knee osteoarthritis and healthy adults using 3D motion analysis and activity monitoring: an exploratory case-control analysis. Orthop Res Rev, 2019, 11: 129–140. [Medline]
7) Ismailidis P, Hegglin L, Egloff C, et al.: Side to side kinematic gait differences within patients and spatiotemporal and kinematic gait differences between patients with severe knee osteoarthritis and controls measured with inertial sensors. Gait Posture, 2021, 84: 24–30. [Medline] [CrossRef]
8) Peixoto JG, de Souza Moreira B, Diz JB, et al.: Analysis of symmetry between lower limbs during gait of older women with bilateral knee osteoarthritis. Aging Clin Exp Res, 2019, 31: 67–73. [Medline] [CrossRef]
9) Hausdorff JM, Rios DA, Edelberg HK: Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil, 2001, 82: 1050–1056. [Medline] [CrossRef]
10) Asai T, Misu S, Sawa R, et al.: The association between fear of falling and smoothness of lower trunk oscillation in gait varies according to gait speed in community-dwelling older adults. J Neuroeng Rehabil, 2017, 14: 5. [Medline] [CrossRef]
11) Ayoubi F, Launay CP, Kabeshova A, et al.: The influence of fear of falling on gait variability: results from a large elderly population-based cross-sectional

study. J Neuroeng Rehabil, 2014, 11: 128. [Medline] [CrossRef]
12) Clermont CA, Barden JM: Accelerometer-based determination of gait variability in older adults with knee osteoarthritis. Gait Posture, 2016, 50: 126–130. [Medline] [CrossRef]
13) Tanimoto K, Takahashi M, Tokuda K, et al.: Lower limb kinematics during the swing phase in patients with knee osteoarthritis measured using an inertial sensor. Gait Posture, 2017, 57: 236–240. [Medline] [CrossRef]
14) Kiss RM: Effect of severity of knee osteoarthritis on the variability of gait parameters. J Electromyogr Kinesiol, 2011, 21: 695–703. [Medline] [CrossRef]
15) Oka T, Asai T, Kubo H, et al.: Association of fear of falling with acceleration-derived gait indices in older adults with knee osteoarthritis. Aging Clin Exp Res, 2019, 31: 645–651. [Medline] [CrossRef]
16) Yakhdani HR, Bafghi HA, Meijer OG, et al.: Stability and variability of knee kinematics during gait in knee osteoarthritis before and after replacement surgery. Clin Biomech (Bristol, Avon), 2010, 25: 230–236. [Medline] [CrossRef]
17) Balasubramanian CK, Clark DJ, Gouelle A: Validity of the gait variability index in older adults: effect of aging and mobility impairments. Gait Posture, 2015, 41: 941–946. [Medline] [CrossRef]
18) Bogen B, Moe-Nilssen R, Aaslund MK, et al.: Muscle strength as a predictor of gait variability after two years in community-living older adults. J Frailty Aging, 2020, 9: 23–29. [Medline]
19) Matsuda K, Ikeda S, Nakahara M, et al.: Factors affecting the coefficient of variation of stride time of the elderly without falling history: a prospective study. J Phys Ther Sci, 2015, 27: 1087–1090. [Medline] [CrossRef]
20) Borg G: Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med, 1970, 2: 92–98. [Medline]
21) Inoue W, Ikezoe T, Tsuboyama T, et al.: Are there different factors affecting walking speed and gait cycle variability between men and women in community-dwelling older adults? Aging Clin Exp Res, 2017, 29: 215–221. [Medline] [CrossRef]
22) Katoh M, Yamasaki H: Comparison of reliability of isometric leg muscle strength measurements made using a hand-held dynamometer with and without a restraining belt. J Phys Ther Sci, 2009, 21: 37–42. [CrossRef]
23) Amano T, Suzuki N: Minimal detectable change for motor function tests in patients with knee osteoarthritis. Prog Rehabil Med, 2018, 3: 20180022. [Medline]
24) Podsiadlo D, Richardson S: The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc, 1991, 39: 142–148. [Medline] [CrossRef]
25) Bellamy N, Buchanan WW, Goldsmith CH, et al.: Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol, 1988, 15: 1833–1840. [Medline]
26) Espinosa SE, Costello KE, Souza RB, et al.: Lower knee extensor and flexor strength is associated with varus thrust in people with knee osteoarthritis. J Biomech, 2020, 107: 109865. [Medline] [CrossRef]
27) Uritani D, Fukumoto T, Myodo T, et al.: The association between toe grip strength and osteoarthritis of the knee in Japanese women: a multicenter cross-sectional study. PLoS One, 2017, 12: e0186454. [Medline] [CrossRef]
28) Thumboo J, Chew LH, Soh CH: Validation of the Western Ontario and Mcmaster University osteoarthritis index in Asians with osteoarthritis in Singapore. Osteoarthritis Cartilage, 2001, 9: 440–446. [Medline] [CrossRef]
29) Kalsi-Ryan S, Rienmueller AC, Riehm L, et al.: Quantitative assessment of gait characteristics in degenerative cervical myelopathy: a prospective clinical study. J Clin Med, 2020, 9: 752. [Medline] [CrossRef]
30) Lord S, Howe T, Greenland J, et al.: Gait variability in older adults: a structured review of testing protocol and clinimetric properties. Gait Posture, 2011, 34: 443–450. [Medline] [CrossRef]
31) Owings TM, Grabiner MD: Measuring step kinematic variability on an instrumented treadmill: how many steps are enough? J Biomech, 2003, 36: 1215–1218. [Medline] [CrossRef]
32) Barden JM, Clermont CA, Kobsar D, et al.: Accelerometer-based step regularity is lower in older adults with bilateral knee osteoarthritis. Front Hum Neurosci, 2016, 10: 625. [Medline] [CrossRef]