



Original Article

Effects of Nordic walking on pelvis motion and muscle activities around the hip joints of adults with hip osteoarthritis

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Abstract. [Purpose] Increased compensatory pelvic movement is remarkable in limping patients with hip osteoarthritis (OA). However, a method of improving limping has not been established. The purpose of this study was to identify the effects of two types of Nordic walking by analyzing the pelvic movement and muscle activities of adults with hip OA. [Subjects and Methods] Ten patients with OA of the hip performed Japanese-style Nordic walking (JS NW), European-style Nordic walking (ES NW), and Ordinary walking (OW), and the muscle activities around the hip joint and pelvic movements were analyzed. [Results] The pelvic rotation angle was significantly larger in ES NW than in JS NW. In the stance phase, hip abductor muscle activity was significantly decreased in JS NW compared to both OW and ES NW. In the swing phase, rectus abdominis muscle activity was significantly increased in both JS NW and ES NW compared to OW and lumbar erector spinae activity was significantly lower in JS NW than in OW. [Conclusion] JS NW style may reduce the compensatory pelvic rotation in patients with hip OA. JS NW might be better for joint protection and prevention of secondary disorders of the hip in OA patients.

Key words: Osteoarthritis, Pelvic movement, Musculoskeletal physiological phenomena

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INTRODUCTION

Osteoarthritis (OA) of the hip is a progressive disease and begins with degradation of the articular cartilage. With the development of disease, limp appears, which can affect the movement of the pelvis¹⁾. Improving the limp associated with OA of the hip can lead an improvement of gait efficiency and hence, quality of life²⁾. Therefore, limp improvement is a desired outcome of physical therapy. However, an effective method for improving the limp associated with hip OA has not yet been established.

One method of improving limping has focused on a walking style called Nordic walking (NW), which has been used in physical therapy, and it is being increasingly used in recent years³⁻⁷⁾. NW is a walking style that uses two specially designed walking poles. The effect of NW intervention has been reported⁸⁻¹⁰⁾; however, there are only few reports on the kinematics of NW. NW was divided into Japanese-style Nordic walking (JS NW) and European-style Nordic walking (ES NW) by the Japan Nordic Walking League. The difference between JS NW and ES NW involves the use of the poles: in JS NW, the walker plants the pole vertically on the ground, like a cane; in contrast, in ES NW, the walker thrusts each pole at a diagonal angle, creating driving force for a more active walking style.

The limp of patients with hip OA also changes pelvic movements and muscle activity around the affected hip^{1, 11, 12)}. In this study, the effects of JS NW on limping by adults with hip OA were examined. Compared to ordinary walking (OW), JS

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NW is associated with significantly decreased trunk movement in healthy adults¹³). It was our hypothesized that JS NW might help to reduce the limp associated with hip OA. Although the effects of JS NW on trunk movements has been clarified, the effect of JS NW on muscle activities around the hip joint and pelvic movements is obscure. In addition, the influence of OW, JS NW, and ES NW on limping associated with hip OA is not clear. Thus, the purpose of this study was to focus on pelvic movements and muscle activities around the hip joints of adults with OA of the hip, and to clarify the effect of OW, JS NW, and ES NW on the improvement of limping.

SUBJECTS AND METHODS

Ten patients with OA of the hip volunteered to participate in this study. Patients were excluded if they had severe metabolic, circulatory, or mental disease. The participants' basic information is described in the results section. Ten participants were classified in to 4 stages according to the Japanese Orthopedic Association (JOA) Committee on Evaluation Criteria. This classification is widely used in Japan, and has been adopted by many studies¹⁴).

The JOA hip score is a common clinical criterion for evaluating hip OA in Japan. The JOA hip score is calculated by summing the category scores of for pain (40 points), range of motion (20 points), walking ability (20 points), and activities of daily life (20 points), with a score of 100 points indicating a perfect score.

This study measured pelvic angles, muscle activities around the hip joint, stride, gait speed, and cadence. For patients with unilateral hip OA, measurements were taken on the affected side, and measurements were taken on the side with the lower JOA hip score in bilateral hip OA.

Pelvic movements were derived from the angular velocities of tilt, obliquity, and rotation. Angular velocity and acceleration were measured using a tri-axial angular accelerometer (MP-M6-06/400B, MicroStone Corporation, Nagano, Japan). Body-fixed sensors (BFSs) containing gyroscopes and accelerometers were positioned at the dorsal side of the pelvis between the posterior superior iliac spines^{15, 16}). BFS data were collected at a sample rate of 1,000 Hz beginning at the same time as EMG measurements. Pelvic angle was determined during the stance phase on the EMG measurement side in each analysis interval. The stance phase and swing phase were identified by analyzing sagittal acceleration in the anteroposterior direction of the acceleration waveform produced by the tri-axial angular accelerometer¹⁷). In addition, the stance phase and swing phase were confirmed by hip abductor EMG activities. The pelvic angle was obtained by integrating the angular velocity measured by the BFS. The minimum and maximum pelvic angles of stance were measured and the maximum amplitude was calculated as the sum of the absolute values. The representative value of each participant was the average of 4 stance phases of maximum deflection.

Muscle activities of the rectus abdominis, spinal erector muscles, rectus femoris, gluteus maximus, gluteus medius, and tensor fasciae latae were measured using Ag/AgCl electrodes (Blue Sensor NF-50, Ambu Inc., Ballerup, Denmark), a pre-amplifier (DPA-11P, Dia Medical System Inc., Tokyo, Japan), amplifier (DPA2008, Dia Medical System Inc., Tokyo, Japan), A/D converter (PowerLab 8/30, ADInstruments, Dunedin, New Zealand), and measurement software (LabChart ver. 7.3.7, ADInstruments, Dunedin, New Zealand).

Muscle activities were determined by EMG measurements during the swing phase and the stance phase in each analysis interval. The EMG measurement device used a sampling frequency of 1,000 Hz, and EMG measurements began at the same time as BFS measurements. The electrode application sites were chosen according to the report of Toshiya as follows¹⁸). The ground electrode was attached over the anterior superior iliac spine. The skin was cleaned with an alcohol-soaked cotton swab before attaching the electrodes in order to reduce the skin resistance. In addition, bipolar surface electrodes were placed at a 2-cm center-to-center distance. EMG waveforms were band-pass filtered (20–500 Hz), before full-wave rectification. For each analysis interval, integrated EMG (IEMG) were calculated. Isometric maximum voluntary contraction was measured, and the IEMG were expressed as % IEMG. The representative value of each participant was calculated as the average of 4 gait cycles.

Each participant performed OW, JS NW (Fig. 1), and ES NW (Fig. 2) twice in a random order. Participants walked at a comfortable speed and were barefoot. The pole length was body height \times 0.64–0.67. Prior to performing each task, JS NW and ES NW were practiced according to the methods of the Nordic Walking League. The JS NW method involves placement of the pole vertically near the heel of the forefoot. The ES NW method involves placement of the pole diagonally near the heel of the forefoot. The load applied to the pole was defined as 10% of body weight. A load measuring device, Nordic walking practice pole (Takei Scientific Instruments, Niigata City, Japan), was used to define the load on the pole during the tasks. A load measuring device, Nordic walking practice pole (Strain amplifier TSA-110, Takei Scientific Instruments, Niigata City, Japan), can set the upper and lower limits of the target load amount, and emits an audible sound when the load is within a specified range.

Stride was measured from the position of the toe at the start to the position of the toe at completion, and was calculated by dividing by the number of steps. The calculated value was divided by the height of each participant and normalized. Gait speed was calculated by dividing the walking distance during each task by the walking time measured using a stopwatch (Casio Inc., Tokyo, Japan). Cadence was calculated by dividing the walking time by the number of steps. Each parameter was determined as the average of two performed tasks to obtain a representative value for each participant.

Data were analyzed using computer software Excel statistics Statcel 3 (Microsoft, Seattle, WA, USA). Pelvic angle,

muscle activities around the hip joint, steps, gait speed, and cadence were compared among the walking styles. Statistical analysis was performed using repeated measures ANOVA. A post-test study was performed using the Tukey-Kramer method. Statistical significance was accepted for values of $p < 0.05$.

The study protocol was explained to all of the participants verbally and in writing, and their written consent was obtained. This study was approved by the Ethical Review Board of the Niigata University of Health and Welfare (approval number 17386-130218).

RESULTS

There were 10 participants, including 9 women and 1 man, with a mean age of 63.3 ± 6.5 years, height 153.3 ± 4.4 cm, weight 53.9 ± 8.7 kg, body mass index 22.8 ± 3.4 , leg length discrepancy 1.0 ± 0.7 cm, and JOA hip score 78.4 ± 8.8 . The affected side was bilateral in 8 participants and unilateral in 2. Six patients with bilateral involvement had a surgical history of bilateral total hip arthroplasty (THA), and 2 patients with bilateral involvement had undergone unilateral THA because the non-THA side was end-stage OA. Two patients with unilateral OA had a surgical history of unilateral THA and end-stage OA.

The pelvic rotation angle was significantly larger in ES NW ($17.5 \pm 6.7^\circ$) than in JS NW ($14.6 \pm 6.8^\circ$) ($p < 0.021$) (Table 1). The pelvic tilt angle and obliquity angle were not significantly different among the walking styles (Table 1).

In the stance phase, gluteus maximus muscle activity was significantly decreased in JS NW ($33.8 \pm 12.3\%$) compared with both OW ($47.0 \pm 18.8\%$) and ES NW ($43.4 \pm 17.3\%$, both $p < 0.000$, Table 2). Gluteus medius activity was significantly lower in both JS NW ($41.3 \pm 22.0\%$) and ES NW ($45.0 \pm 22.4\%$) than in OW ($55.0 \pm 25.1\%$) (both $p < 0.001$, Table 2). Tensor fasciae latae activity was significantly decreased in JS NW ($31.0 \pm 25.7\%$) compared with that in OW ($40.5 \pm 28.1\%$) ($p < 0.021$, Table 2).

In the swing phase, rectus abdominis muscle activity was significantly increased in both JS NW ($19.7 \pm 9.6\%$) and ES NW ($19.3 \pm 9.2\%$) compared with that in OW ($15.9 \pm 9.7\%$) (all $p < 0.010$, Table 2). Lumbar erector spinae activity was significantly lower in JS NW ($32.0 \pm 17.8\%$) than in OW ($38.1 \pm 20.3\%$) ($p < 0.005$, Table 2).

Stride distance was significantly larger in ES NW ($39.2 \pm 3.4\%$) than in OW ($37.9 \pm 3.4\%$) ($p < 0.015$, Table 3). There were no significant differences among the walking styles in gait speed ($p = 0.247$) or cadence ($p = 0.066$) (Table 3).

DISCUSSION

This study analyzed pelvic angle, muscular activities around the hip joint, and several gait parameters of three different gait styles (JS NW, ES NW and OW), and found there are biomechanical and physiological differences among the walking

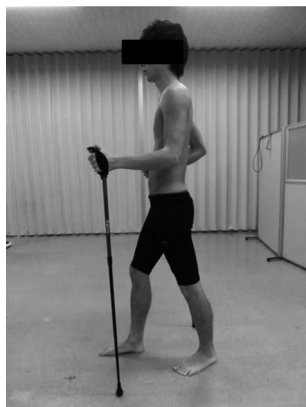


Fig. 1. Japanese-style Nordic walking (JS NW)

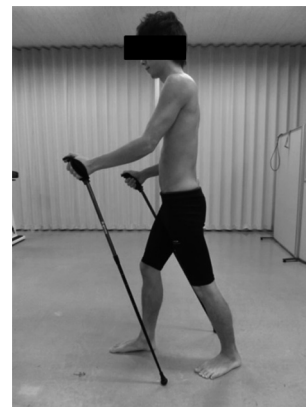


Fig. 2. European-style Nordic walking (ES NW)

Table 1. Pelvic angles according to walking style

Pelvic angle (°)	OW	JS	ES	Analysis of variance Tukey-Kramer
Tilt angle	5.3 ± 1.7	5.7 ± 3.7	5.5 ± 3.4	
Obliquity angle	7.5 ± 4.0	8.2 ± 2.9	8.4 ± 3.1	
Rotation angle	16.5 ± 7.8	$14.6 \pm 6.8\ddagger$	$17.5 \pm 6.7\ddagger$	JS<ES

Values are shown as the mean \pm SD. $\ddagger p < 0.05$; significant difference, JS vs. ES.

styles. Although the number of participants was small, the pathological condition of each participant was not consistent, the results of this study indicate that JS NW decreases compensatory pelvic rotation, protects the hip joint by decreasing the muscle activity of the hip abductors, and inhibits overused low back muscles. Therefore, the JS NW style might be an effective clinical intervention for improving the limp of patients with hip OA.

Although no significant differences in pelvic angle (tilt, obliquity, and rotation) were noted between OW and JS NW or ES NW, the pelvic rotation angle was significantly increased in ES NW compared with that in JS NW. The pelvic rotation angle increased due to the difference in pole use during NW. The two methods of NW are fundamentally different walking styles: in JS NW, the pole is used vertically like a cane, whereas in ES NW, the pole is thrust into the ground diagonally. According to Elhtman, the body's balance during gait is controlled by the rotation of the upper extremities and trunk on the side opposite to pelvic rotation¹⁹). Because of the difference in the position of the pole during ground contact, ES NW is considered to be a gait style in which propulsion is acquired by large arm swings. In addition, stride was significantly larger in ES NW than in OW. It is clear that the driving force of ES NW was derived from the use of the pole.

In the analysis of muscle activities in the stance phase, the hip abductor muscles were found to have significantly lower activities in JS NW than in OW or ES. Once again, lower hip abductor muscle activity could be attributed to the walking style of JS NW, which involves planting the pole on the ground like a cane. The JS NW pole placement elicits a ground reaction force, which complements the activity of the hip abductors, thereby decreasing hip abductor muscle activity²⁰). In contrast, in ES NW, only the activity of the gluteus medius was decreased. During ES NW, the pole is thrust diagonally backwards; therefore, compared with JS NW, the ground reaction force of ES NW moment in the vertical direction is lower. Thus, only the activity of the gluteus medius was decreased.

During the swing phase, rectus abdominis activity increased significantly in both JS NW and ES NW compared with that in OW. A ground reaction force generated by the poke of a cane was reported by Neumann²⁰), and it is conceivable that the use of pole in NW also creates a ground reaction force. In the case of additional ground reaction force generated by poking the pole, a perturbation force may act on the trunk due to the diagonal force generated from the ground toward the center of gravity. Therefore, there is a demand to maintain the center of gravity of the body against the ground reaction force, which is generated by the use of the pole. Hodges reported that the activity of the rectus abdominis muscle acts to control body sway²¹). It is thought that rectus abdominis muscle activity increases to control the center of gravity with respect to the ground reaction force due to the use of the pole. In addition, the lumbar erector spinae activity was significantly lower in JS NW than

Table 2. Stance phase and swing phase muscle activity according to walking style

Muscle (%)	stance phase	OW	JS	ES	Analysis of variance Tukey-Kramer
	swing phase				
Rectus abdominis	stance phase	16.4 ± 11.2	17.0 ± 9.4	17.2 ± 9.1	OW<JS, OW<ES
	swing phase	15.9 ± 9.7*†	19.7 ± 9.6*	19.3 ± 9.2†	
Spinal erector	stance phase	29.3 ± 18.0	24.0 ± 17.9	27.6 ± 18.4	OW>JS
	swing phase	38.1 ± 20.3*	32.0 ± 17.8*	35.0 ± 17.9	
Rectus femoris	stance phase	22.3 ± 15.4	25.2 ± 20.0	25.7 ± 19.9	
	swing phase	17.5 ± 12.3	18.6 ± 14.6	21.2 ± 18.8	
Gluteus maximus	stance phase	47.0 ± 18.8*	33.8 ± 12.3*‡	43.4 ± 17.3‡	OW>JS, ES>JS
	swing phase	16.5 ± 6.3	16.1 ± 5.4	17.0 ± 5.0	
Gluteus medius	stance phase	55.0 ± 25.1*†	41.3 ± 22.0*	45.0 ± 22.4†	OW>JS, OW>ES
	swing phase	22.8 ± 12.2	24.5 ± 12.4	25.7 ± 13.5	
Tensor fasciae latae	stance phase	40.5 ± 28.1*	31.0 ± 25.7*	32.3 ± 24.3	OW>JS
	swing phase	15.2 ± 9.3	15.7 ± 10.2	17.8 ± 12.6	

Values are shown as the mean±SD. *p<0.05; significant difference, OW vs. JS. †p<0.05; significant difference, OW vs. ES. ‡ p<0.05; significant difference, JS vs. ES.

Table 3. Stride, gait speed, and cadence according to walking style

stride, gait speed, cadence	OW	JS	ES	Analysis of variance
				Tukey-Kramer
Stride (%)	37.9 ± 3.4†	38.6 ± 3.8	39.2 ± 3.4	OW<ES
Gait speed (cm/sec)	79.5 ± 18.0	75.4 ± 22.3	78.5 ± 23.0	
Cadence (step/sec)	1.3 ± 0.2	1.2 ± 0.2	1.2 ± 0.2	

Values are shown as the mean±SD. †p<0.05; significant difference, OW vs. ES.

in OW. An increase in abdominal rectus muscle activity leads to an increase in intra-abdominal pressure, which increases trunk stability²²). In addition, an increase of trunk stabilization results in a decrease of back muscles activity.

The hypothesis of this study was that JS NW would have an influence to pelvic movements and improve the limping of those with OA of the hip. In general, flexion in OA hips during gait is limited due to ROM restriction, and compensatory pelvic rotation is increased at the time of walking. The present findings showed decreased pelvic rotation angle in JS NW. This is considered to lead a reduction in compensatory pelvic rotation in the patients with hip OA, which indicates improvement of limping.

With regard to muscle activity, hip abductor muscle activity reduced, rectus abdominis activity increased, and lumbar erector spine activity decreased during JS NW. The hip abductors are significantly involved in the generation of joint compression force, so JS NW, which decreases the activity of the hip abductors, might be able to protect the joint.

Lumbar spine disease often occur in patients with OA of the hip with corresponding low back pain^{23–25}). One of the causes of low back pain is overactive low back muscle activity. In JS NW, the activity of the rectus abdominis increases, since the activity of lumbar erector spine decreases. JS NW might be a walking style suitable for the prevention of secondary disorders such as low back pain, because of the change in trunk muscular activity.

Exercise therapy for OA of the hip is effective. Although excessive exercise can trigger pain, exercise therapy is necessary in pain-free movement. The results of this study indicate that the JS NW style offers better joint protection and trunk stability compared to OW and ES NW. Therefore, JS NW is suggested as a walking style that can prevent hip and low back pain, and may be an effective exercise therapy for the prevention of disability in patients with hip OA.

This study had several limitations. The present study demonstrated only the immediate effect of walking styles on the hip; hence, a study with a longer treatment period is needed to verify our findings. However, the findings are significant, since a beneficial effect was confirmed in hip OA patients, despite the small sample size.

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