The Journal of Physical Therapy Science

Original Article

Influence of kyphosis posture on postural control and lower limb mechanical load immediately after stopping walking

Chihiro Niibo, RPT, MS[1]*, Tomoaki Matsuda, RPT, MS[2], Hidefumi Fukuda, RPT, MS[1], Hiroshi Katoh, RPT, PhD[3]

[1] Department of Rehabilitation, Ogura Hospital: 27-22 Kasanohara-cho, Kanoya city, Kagoshima 893-0023, Japan
[2] Department of Rehabilitation, Shishime Orthopedics Hospital, Japan
[3] Graduate School, Yamagata Prefectural University of Health Sciences, Japan

Abstract. [Purpose] This study aimed to clarify the characteristics of joint moment and force for postural control performance after stopping walking under two conditions. [Participants and Methods] A total of 18 healthy males participated in this study. The joint moment and power were compared between the normal and kyphosis postures after stopping walking based on the critical time interval as calculated by stabilogram diffusion analysis. [Results] The polarity of the joint moment in both postures was different in the knee and hip extension–flexion directions, the absolute value being higher in the kyphosis posture than in the normal one. The hip and knee joint powers were negative in the normal posture but positive in the kyphosis posture; these values were higher in the kyphosis posture than the normal one. [Conclusion] The polarity of the joint moment of the hip and knee joints in the direction of flexion and extension differed from the normal one due to the postural changes caused by the kyphosis posture. The postural controls between the two conditions were considered different. The leading limb was thought to be an important braking action in stopping walking.
Key words: Stopping walking, Joint moment and power, Kyphosis posture

INTRODUCTION

In daily living activities, the walking state needs to be changed according to various situations, such as starting to walk, acceleration, deceleration, change of direction, and stopping[1]. To move safely in daily life, we need not only the ability to walk but also the ability to stop walking[2]. The motion involved in stopping walking is a transitional movement that is often performed in daily life; however, this nonperiodic transitional movement is considered difficult for the elderly and disabled[3]. During this transitional movement, patients with cerebellar and vestibular dysfunction use excessive energy to stop walking and have difficulty controlling their center of gravity (COG) sway in left (Lt) and right (Rt) directions[4]. Moreover, the number of steps taken before stopping and the duration of stopping are increased in elderly patients[5].

Stabilogram diffusion analysis (SDA) is a method to evaluate postural sway[6]. SDA revealed that elderly demonstrated a significantly greater amount of sway in the anteroposterior direction in the short-term region and greater muscle activity during static standing than those demonstrated by young people[7]. Additionally, the postural control mechanism in patients with Parkinson's disease shows an increase in medial sway compared with those in healthy elderly people, which is associated with a history of falls and decreased balance[8]. However, previous studies have only analyzed posture in the resting position, and no studies have examined the factors of postural control in the center of the pressure sway from a kinematic perspective

using SDA. SDA is characterized by its ability to calculate the time required to maintain stability, also called the critical point. Previous studies have reported that changes in the spinal column affect stability. Lumbar kyphosis is a determinant of postural balance or the occurrence of falls[9], and kyphotic postures have greater postural sway and use a hip joint strategy to maintain balance[10]. Based on these points, it can be confirmed that changes in the spinal column affect stability and it takes time to maintain stability. In addition, postural sway is likely to be greater, and to control it, greater lower limb joint moment and force activity may be required in the kyphosis posture than in the normal posture. In this study, we aimed to clarify the characteristics of the joint moment and power for posture control performance at the time of stopping walking from the boundary point calculated by SDA under two conditions: normal posture and kyphosis of the spine (kyphosis posture); the latter is a common posture among elderly people in Japan[11].

PARTICIPANTS AND METHODS

Participants were 18 healthy males (mean ± standard deviation; age, 25.5 ± 6.3 years; height, 169.3 ± 4.2 cm; weight, 67.8 ± 10.8 kg) without previous orthopedic or neurological disease. This study was conducted with approval from the Ethics Committee of Kyushu University of Nursing and Social Welfare (30-020).

All measurements were taken using a three-dimensional motion analysis system (VICON MX-T, Vicon Motion Systems Ltd., Oxford, UK) with 10 infrared cameras and 2 force plates (AMTI Inc., Watertown, MA, USA) with a sampling rate of 100 Hz. Thirty-three reflective markers were placed on specific anatomic position, including bilaterally on the acromion, elbow, styloid process of the radius, iliac crest, hip, anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral femoral condyle, medial femoral condyle, lateral shank, lateral malleolus, lateral malleolus, first metatarsal head, fifth metatarsal head, calcaneus, and Rt scapula (Fig. 1). The force plates were defined as x for the Lt–Rt component, y for the anterior–posterior component, and z for the vertical component of the coordinate system.

Participants walked along a 7-m long walkway and stopped walking with the Lt and Rt legs stopping at the two force plates, in that order. Stopping walking was defined as the point where the floor reaction force appeared after the Rt leg touched the floor; moreover, the measurement of the center of foot pressure was started from this point. The static stance posture was maintained for 30 sec from the beginning of the stop walking motion. The upper limbs were held to the side of the body, and the line of sight was directed at a screen (2 m ×v2 m) placed 3 m in front of the participant. The walking speed with a stride length of 0.7 m and a walking rate of 117 steps/min was specified. The stride width was not regulated. The walking rate was measured using an electronic metronome ME-110 (YAMAHA Inc., Shizuoka, Japan), and markers were placed on the ground to serve as a guide. Three practice sessions were conducted prior to actual measurements. Two postures were used, normal and kyphosis. The angle of the brace was adjusted to achieve a flexed position using a Jewett-type orthosis (Fig. 2), and the length was adjusted so that the abdomen was fixed, and the kyphosis posture was maintained by three-point fixation of the sternum, abdomen, and back. In this study, orthosis was used to maintain the total kyphosis posture, with the entire spinal column exhibiting kyphosis.

Using Vicon Nexus (v.1.7.1), the coordinate data of the infrared reflective marker measured using the three-dimensional motion analyzer was processed by applying a Butterworth filter with a cutoff frequency of 6 Hz. The COP data measured
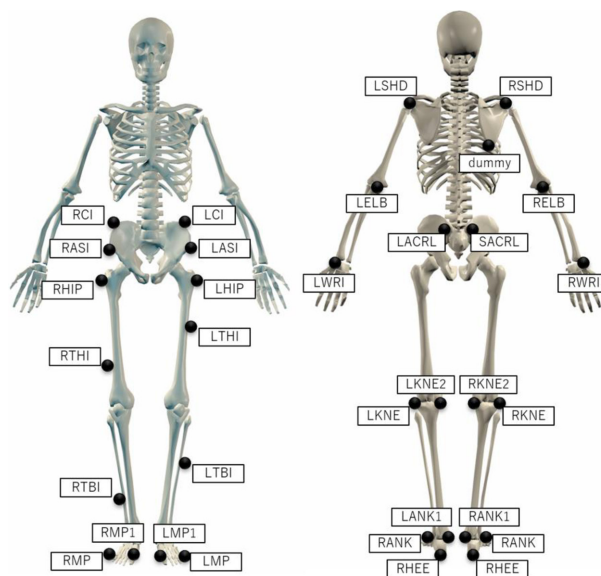

Fig. 1.   Vicon reflective marker placement.

J. Phys. Ther. Sci. Vol. 34, No. 3, 2022

194

from the force plates were processed by applying a Butterworth filter with a cutoff frequency of 10 Hz. Vicon Body Builder (v.3.6.1) was used to calculate the moment and power in each joint from the data obtained using the three-dimensional motion analysis system. Joint moments were internal in this study, with positive values defined as plantar flexion, pronation, and abduction for the ankle joint; extension, adduction, and internal rotation for the knee joint; and extension, abduction, and internal rotation for the hip joint. The values for the joint moment (in Newton-meters) and power (in Watts) were normalized with respect to participant body mass (in kg). Based on a previous study[6], the point at which the slope of the curve obtained by SDA shows a marked change is defined as the critical time interval (CTI), and the curve is divided into two regions, the short-term region and long-term region, after the CTI. The slope (diffusion coefficient) was calculated from the regression line in the short-time region from 0 seconds to the critical point.

CTI was calculated by moving on the time axis in increments of 0.05 sec and obtaining regression lines for the short-term and long-term regions.

The mean residuals of both lines were then minimized using the least-squares criterion to fit the two regions[12]. The average values of moment and power for the time from 0 sec to CTI were calculated (Fig. 3).

Statistical analyses were performed using the IBM SPSS Statistics software v.23 (IBM Japan Inc, Tokyo, Japan) for comparing the average values of CTI, diffusion coefficients of short-term region (Ds), moment, and power between normal and kyphosis postures. The Shapiro–Wilk test for normality was used to examine normality, and two-sample t-test and Wilcoxon's signed-rank test were used to examine differences between groups. P values of <0.05 were considered statistically significant.

RESULTS

There was no significant difference in the CTI of normal and kyphosis postures (Table 1). Ds was significantly higher in the kyphosis posture (Table 1). The knee joint of the Lt lower extremity (LE) showed different polarity in terms of the extension–flexion direction in both postures, and the absolute value of the moment was significantly higher in the kyphosis posture. The abduction moment was significantly higher in the normal posture. The hip joint exhibited different polarity in the extension–flexion direction in both postures, and the absolute value of the moment was significantly higher in the normal posture. The abduction moment was significantly higher in the kyphosis posture.

The ankle abduction moment of Rt LE was significantly higher in the kyphosis posture than in the normal posture. The knee joint showed different polarities in the extension–flexion direction in both postures, and the absolute value of the moment was significantly higher in the kyphosis posture. The hip joint showed different polarity in the extension–flexion in both postures, and the absolute value of the moment was significantly higher in the kyphosis posture. The abduction moment was significantly higher in the kyphosis posture. The polarity of the two postures was different in the internal–external rotation directions, and the absolute value of the moment was significantly higher in the normal posture (Table 2).

The hip joint power of the Lt LE was negative in the normal posture, positive in the kyphosis posture, and significantly higher in the kyphosis posture. The ankle joint power of the Rt LE was negative in both the postures and significantly higher in the kyphosis posture. Knee power was negative in the normal posture, positive in the kyphosis posture, and significantly higher in the kyphosis posture (Table 3).
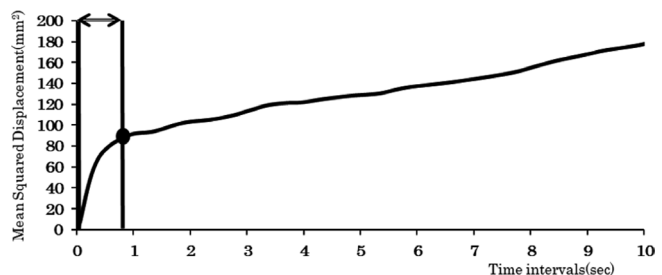

Fig. 3. Example of calculation of joint moment and power calculated using stabilogram diffusion analysis. The average values of each joint moment and power are calculated from the time 0 sec to critical time interval (CTI) (arrow) based on CTI (black circle in the figure).

Fig. 2. Orthotic device used to maintain kyphosis posture.

Table 1. Critical time interval comparison and diffusion coefficients of short-term region

	Normal	Kyphosis	
CTI (sec)	0.76 ± 0.27	0.79 ± 0.26	
Ds (mm²/sec)	119.87 ± 73.25	195.01 ± 94.87	**

Mean ± standard deviation. **p<0.01.

Table 2. Comparison of mean lower extremity joint moments from stopping walking to critical time interval

Joint moment (Nm/kg)		Direction	Normal	Kyphosis	
Lt. LE	Ankle	PF–DF	0.29 ± 0.08	0.26 ± 0.17	
		PRO–SUP	0.18 ± 0.06	0.17 ± 0.04	
		ABD–ADD	0.14 ± 0.05	0.15 ± 0.03	
	Knee	EXT–FLEX	−0.006 ± 0.06	0.15 ± 0.04	**
		ABD–ADD	−0.36 ± 0.23	−0.33 ± 0.08	*
		IR–ER	0.09 ± 0.02	0.08 ± 0.02	
	Hip	EXT–FLEX	−0.23 ± 0.08	0.008 ± 0.16	**
		ABD–ADD	0.40 ± 0.09	0.34 ± 0.08	**
		IR–ER	0.07 ± 0.02	0.01 ± 0.04	**
Rt. LE	Ankle	PF–DF	0.23 ± 0.10	0.25 ± 0.11	
		PRO–SUP	0.15 ± 0.02	0.16 ± 0.02	
		ABD–ADD	0.11 ± 0.03	0.13 ± 0.04	*
	Knee	EXT–FLEX	−0.02 ± 0.10	0.10 ± 0.17	*
		ABD–ADD	−0.34 ± 0.06	−0.37 ± 0.08	
		IR–ER	0.06 ± 0.03	0.06 ± 0.03	
	Hip	EXT–FLEX	−0.05 ± 0.11	0.16 ± 0.13	**
		ABD–ADD	0.33 ± 0.09	0.39 ± 0.11	*
		IR–ER	0.03 ± 0.02	−0.008 ± 0.04	**

Mean ± standard deviation. Lt.: Left; Rt.: Right; LE: lower extremity; PF–DF: Planter Flexion–Dorsal Flexion; PRO–SUP: Pronation–Supination; ABD–ADD: Abduction–Adduction; EXT–FLEX: Extension–Flexion; IR–ER: Internal Rotation–External Rotation.
*p<0.05, **p<0.01.

Table 3. Comparison of mean lower extremity joint power from stopping walking to critical time interval

Joint power (W/kg)		Normal	Kyphosis	
Lt. LE	Ankle	−0.04 ± 0.02	−0.04 ± 0.02	
	Knee	−0.01 ± 0.02	−0.02 ± 0.03	
	Hip	−0.04 ± 0.02	0.002 ± 0.03	**
Rt. LE	Ankle	−0.01 ± 0.02	−0.03 ± 0.04	*
	Knee	−0.01 ± 0.03	0.02 ± 0.03	*
	Hip	−0.002 ± 0.03	0.005 ± 0.02	

Mean ± standard deviation. Lt.: Left; Rt.: Right; LE: lower extremity. *p<0.05, **p<0.01.

DISCUSSION

Stopping walking is the movement that connects the dynamic state of walking and the static state of standing[13], and leads to a change in the gait pattern. In this study, we calculated the COP sway generated during the motion to stop walking using SDA and examined its influence on posture control in terms of joint moment and power.

Contrary to our hypothesis, there was no significant difference in the time factor by CTI. CTI is the point of transition from the short-term region to the long-term region. The short-term region is the time interval required to maintain stability, and it is thought that if the diffusion coefficient in this region is high, the postural sway is greater[6]. To control this sway, the elderly show more than twice the muscle activity shown by young individuals involving the biceps femoris, vastus lateralis, and tibialis anterior muscles[7]. In healthy young participants, the angular velocities of the ankle and hip joints cancel each

J. Phys. Ther. Sci. Vol. 34, No. 3, 2022

196

other out[14], and the posture of the kyphosis in this study is also considered to be influenced by this compensatory relationship and the control of LE joints. CTI was not significantly different, but the Ds was significantly higher in the kyphosis posture, indicating that the sway was greater in this posture. The influence of joint moment and power is considered to control this postural sway. In terms of joint moments, the bilateral knee joint and hip joint flexion–extension moments were significantly different, with the normal posture showing a flexion moment and the kyphosis posture showing an extension moment. In the kyphosis posture, the COG of the upper body is located in the rear due to kyphosis of the spinal column, and knee joint extension moment increases[15]. Consequently, the COG is easily displaced from the base of support. Therefore, the kyphosis posture requires extension moments for the knee and hip joints. In this case, neither the knee joint nor the hip joint can be extended, and the COG has difficulty passing from the front of the knee joint axis. The hip abduction moment was significantly affected by the Lt hip joint in the normal posture and by the Rt hip joint in the kyphosis posture. In this study, stopping walking was performed in the order of the Lt and Rt legs. The leading limb, which is grounded first when stopping walking, effectively produces a high braking force[5], and the muscles of the leading limb are active for longer than those of the trailing limb during the stopping motion[16]. In addition, the gluteus medius and erector spinae muscles, which prevent the trunk from moving forward, decelerate pelvic rotation, reduce the amount of exercise, and stabilize the COG[13]. This suggests that the hip abduction moment by the Lt LE, which is the leading limb, effectively acts in the normal posture to control COG sway. In the kyphosis posture, it is difficult to control propulsion with the leading limb at the time of stopping walking, and thus, stability cannot be obtained. Therefore, it is considered that the abduction moment by the trailing limb stabilizes the body sway. Regarding joint power, there were significant differences in hip power for the Lt LE and ankle and knee power for the Rt LE. For joint power, positive values indicate concentric contraction and negative values indicate eccentric contraction[17]. The hip joint power of the Lt LE was negative in the normal posture and positive in the kyphosis posture, indicating that eccentric contraction operated in the normal posture and concentric contraction functioned in the kyphosis posture after stopping walking. The knee joint power of the Rt LE was also negative in the normal posture and positive in the kyphosis posture, indicating that eccentric contraction operates in the normal posture and concentric contraction functions in the kyphosis posture after stopping walking. While stopping walking, it is necessary to increase the braking force after the lower limbs contact and decrease the push-off before stopping[18]. In both conditions, extension movement occurred, but the normal posture acted as a brake against extension movements, whereas the kyphosis posture caused movement was upward, which may have affected the sway of the static standing posture after stopping walking. In the kyphosis posture, the power of the Rt ankle joint was highly negative; it was considered that the action of efferent contraction by the plantar flexor muscle was required from the normal posture in order to control the agitation of the body and obtain stability.

This study showed the importance of the leading limb as a braking action of propulsive force at the time of stopping walking and that joint power was generated by the hip joint in the normal posture and by the ankle joint in the kyphosis posture. Moreover, the polarity of the joint moment of the hip and knee joints in the direction of flexion and extension differed depending on the posture change due to the kyphosis posture. Since the COG tends to be located backward in the kyphosis posture, the posture control is different from the normal posture. This study had certain limitations. As stopping walking was planned in this study, postural control may be different in unplanned stopping walking. Additionally, this study was conducted in healthy young adults, which may differ from the actual control of patients with kyphosis.

Conflicts of interest

None.

REFERENCES

1) Hagiwara H, Asakura T, Wada N, et al.: The influence of a dual task on the termination on gait by healthy adults. Rigakuryoho Kagaku, 2015, 30: 679–682 (in Japanese). [CrossRef]

2) Koseki Y, Takakura Y, Kunisawa Y, et al.: Reliability and validity of the 5-meter walk and stop test, and the effect of lower extremity muscle strength [Translated from Japanese]. Rinsho Rigakuryoho Kenkyu, 2017, 34: 19–22 (in Japanese).

3) Ryckewaert G, Delval A, Bleuse S, et al.: Biomechanical mechanisms and centre of pressure trajectory during planned gait termination. Neurophysiol Clin, 2014, 44: 227–233. [Medline] [CrossRef]

4) O'Kane FW, McGibbon CA, Krebs DE: Kinetic analysis of planned gait termination in healthy subjects and patients with balance disorders. Gait Posture, 2003, 17: 170–179. [Medline] [CrossRef]

5) Tirosh O, Sparrow WA: Gait termination in young and older adults: effects of stopping stimulus probability and stimulus delay. Gait Posture, 2004, 19: 243–251. [Medline] [CrossRef]

6) Collins JJ, De Luca CJ: Open-loop and closed-loop control of posture: a random-walk analysis of center-of-pressure trajectories. Exp Brain Res, 1993, 95: 308–318. [Medline] [CrossRef]

7) Laughton CA, Slavin M, Katdare K, et al.: Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. Gait Posture, 2003, 18: 101–108. [Medline] [CrossRef]

8) Mitchell SL, Collins JJ, De Luca CJ, et al.: Open-loop and closed-loop postural control mechanisms in Parkinson's disease: increased mediolateral activity during quiet standing. Neurosci Lett, 1995, 197: 133–136. [Medline] [CrossRef]

9) Ishikawa Y, Miyakoshi N, Kasukawa Y, et al.: Spinal curvature and postural balance in patients with osteoporosis. Osteoporos Int, 2009, 20: 2049–2053.

[Medline] [CrossRef]

10) Lynn SG, Sinaki M, Westerlind KC: Balance characteristics of persons with osteoporosis. Arch Phys Med Rehabil, 1997, 78: 273–277. [Medline] [CrossRef]

11) Takai I, Shutou H, Miyano M, et al.: Postural change and posture control with aging. Nihon Seirijinrui Gakkaishi, 2001, 6: 11–16.

12) Tanaka H, Uetake T, Kuriki S, et al.: Changes in center-of-pressure dynamics during upright standing related to decreased balance control in young adults: fractional Brownian motion analysis. J Hum Ergol (Tokyo), 2002, 31: 1–11. [Medline]

13) Hase K, Stein RB: Analysis of rapid stopping during human walking. J Neurophysiol, 1998, 80: 255–261. [Medline] [CrossRef]

14) Aramaki Y, Nozaki D, Masani K, et al.: Reciprocal angular acceleration of the ankle and hip joints during quiet standing in humans. Exp Brain Res, 2001, 136: 463–473. [Medline] [CrossRef]

15) Nakabo T, Fukui T: Clinical motion analysis in orthopedic [Translated from Japanese]. Rigakuryoho J, 2009, 43: 1081–1087 (in Japnaese).

16) Bishop M, Brunt D, Pathare N, et al.: The effect of velocity on the strategies used during gait termination. Gait Posture, 2004, 20: 134–139. [Medline] [CrossRef]

17) Czerniecki JM, Gitter A, Munro C: Joint moment and muscle power output characteristics of below knee amputees during running: the influence of energy storing prosthetic feet. J Biomech, 1991, 24: 63–75. [Medline] [CrossRef]

18) Jaeger RJ, Vanitchatchavan P: Ground reaction forces during termination of human gait. J Biomech, 1992, 25: 1233–1236. [Medline] [CrossRef]

J. Phys. Ther. Sci. Vol. 34, No. 3, 2022

198