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Original Article

Does decrease of the thoracic kyphosis influence decrease knee adduction moment during gait? A preliminary study of a healthy population

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Abstract. [Purpose] The purpose of this study was to investigate the influence of a decrease in thoracic kyphosis angle on the knee adduction moment during gait in healthy young individuals. [Subjects and Methods] Twenty-nine healthy adults, consisting of 15 males and 14 females (21.6 ± 1.1 years old), participated. The draw-in maneuver was used to decrease thoracic kyphosis, and thoracic kyphosis was measured using a SpinalMouse during normal standing and standing with the draw-in maneuver. The participants were required to maintain the draw-in maneuver during gait. A 3-D motion analysis system and a force plate were used to obtain knee adduction moment. [Results] Thoracic kyphosis angles during the draw-in maneuver (41.0 ± 7.4 degrees) were significantly decreased compared with the angles during normal standing (43.0 ± 7.9 degrees). Although the knee adduction moment during gait with the draw-in maneuver was not significantly decreased compared with that during level gait, in the 20 subjects who had decreased kyphosis due to the draw-in maneuver, the 1st peak knee adduction moment ($55.7 \pm 24.3 \times 10^{-3}$) with the draw-in maneuver was significantly decreased compared with the knee adduction moment ($57.0 \pm 16.3 \times 10^{-3}$) during level gait. [Conclusion] Knee adduction moment in the case of a decreased thoracic kyphosis angle due to the draw-in maneuver was decreased compared with that during level gait.
Key words: Posture, Gait, Knee

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INTRODUCTION

Knee varus deformity caused by knee osteoarthritis (knee OA)[1)] and thoracic kyphosis (TK) caused by osteoporosis[2)] are often seen in clinical settings as posture malalignment in the elderly. Clinically, good posture during walking and activities of daily living (ADL) is generally recommended[3, 4)] for the elderly with posture malalignment. However, it is unclear whether correcting the malalignment induces positive effects on bones and joints. Therefore, one of the clinical questions based on the high prevalence of bone and joint disease in the elderly is whether or not a decrease of TK is related to a decrease of knee varus deformity (knee adduction moment: KAM) during gait in patients with knee OA[5)].

As the first preliminary study to address the abovementioned clinical question, we investigated whether or not a decrease in TK angle affects the decrease in KAM in healthy subjects. To produce an acute decrease in TK during gait, the draw-in maneuver (DI), which is expected to decrease TK (unloading of the spine) due to increasing inter-abdominal pressure[6)], was applied in the present study. However, because the effect of DI applied to decrease TK is not known, its effect was also investigated in the present study.

SUBJECTS AND METHODS

Twenty-nine healthy adults, consisting of 15 males and 14 females, participated in the current study. Their average age, height and weight were 21.6 ± 1.1 years, 163.4 ± 7.6 cm, and 59.7 ± 10.4 kg, respectively. Subjects were recruited from the student body of the Department of Rehabilitation and Care of Seijoh University using a leaflet and poster on a bulletin board. The inclusion criteria were 1) no current musculoskeletal pain and disorder and 2) no history of musculoskeletal surgery. Prior to participation, all participants including those in the pilot study were informed as to the nature of the study, and their informed consent was obtained as approved by the Ethics Committee of Seijoh University.

DI was used to decrease TK in the present study. The verbal instruction for applying DI was "Please draw in your belly slightly." The abdominal circumferences of the 29 subjects were measured by a tape measure at the level of the navel in a standing position. The averages of three measurements were used as the final data. The average change in abdominal circumference caused by DI was 2.1 ± 0.1 cm.

A SpinalMouse (Idiag AG, Volketswil, Switzerland) was used to assess the TK angle (T1-2 to T11-12)[7)] in the standing position and in the standing position with DI. The TK

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angle was measured three times, and the average data were used in the final analysis.

Three-dimensional trajectory data were obtained using a 10-camera motion analysis system (Venus 3D; Nobby Tech, Tokyo, Japan). Trajectory data were sampled at 100 Hz and digitally recorded. Ground reaction forces were collected at a rate of 100 Hz using a force plate (AccuGait; AMTI, MA, USA), and the force plate and 3D motion analysis system were synchronized. Twenty-five reflective sphere markers (7 mm diameter) were attached to various anatomical locations and thigh and lower leg plates.

The subjects performed tasks while barefoot were allowed to walk at a controlled speed within ±5% of a standard speed set for Japanese[8] as measured with the second sacrum marker. They were then asked to walk along a 6-m walkway, and three successful trials were recorded.

A 4-link model with four segments for the pelvis, thigh, shank (lower leg), and foot was developed. The segments were estimated using global optimization[9], and the model was customized to each subject using their marker data measured during static calibration. These marker coordinates were used to define segment-embedded reference frames for the associated body segments[10]. The inertial properties for each limb segment were based on Japanese inertial characteristics[11]. Knee joint centers were defined as the midpoint between the lateral and medial femoral epicondyle.

External KAMs were calculated using inverse dynamics. KAMs were normalized to body mass and leg length (the height of the trochanter marker during static calibration)[12]. The KAMs from the three trials were averaged for analysis. All data were normalized to 100% of a gait cycle with 0% heel contact of the measured leg. The first and second peaks of KAM during the stance phase (0–30 and 30–60% of the gait cycle) were obtained[13]. The length of the lever arm for KAM was calculated as the perpendicular distance between the ground reaction force vector and the knee joint center in the frontal plane. Lever arms were determined at the first and second peaks of the KAM.

Analyses and measurements were performed in the following order: analysis of level gait, TK angle measurement without and with DI, and gait analysis with DI. After the assessment of TK, nonelastic tape was used around the body at the navel to maintain the circumference during gait with DI. A tape measure was used to confirm 2.1 cm shortening of the abdominal circumference during DI.

To determine differences between the TK angle and KAM during gait with or without DI, the paired t-test was performed with the significance level set at $p < 0.05$. All statistical analyses were performed with SPSS, Version 16.0 (IBM Japan, Tokyo, Japan).

RESULTS

The speeds of level gait and gait with DI were 1.39 ± 0.04 and 1.38 ± 0.04 (m/s), respectively, and the difference between them was not significant (Table 1).

The TK angles during standing and standing with DI were 43.0 ± 7.9 degrees and 41.0 ± 7.4 degrees, respectively, and the difference between them was significant ($p<0.05$). Twenty participants had decreased kyphosis angles due to DI (average change: 4.2 ± 2.6 degrees), and nine participants had increased kyphosis angles due to DI (average change: −3.7 ± 2.6 degrees) (Table 1).

Table 1. Gait speed and thoracic kyphosis angle in standing without and with the draw-in maneuver

	Gait ($\times 10^{-3}$)	Gait with DI ($\times 10^{-3}$)
Gait speed (m/s)	1.39 ± 0.04	1.38 ± 0.04
Thoracic kyphosis angle		
All subjects (n=29)*	43.0 ± 7.9	41.0 ± 7.4
Group 1 (n=20)*	43.0 ± 7.5	38.9 ± 6.5

Group 1: 20 subjects who decreased thoracic kyphosis with the draw-in maneuver (DI). *$p<0.05$. Values are shown as the mean±SD

The 1st and 2nd peaks of KAM are shown in Table 2; there were no significant differences in any subjects. The KAMs of the twenty participants who had a decreased TK angle are also shown in Table 2, and the 1st peak of KAM during gait with DI was significantly decreased compared with the KAM during level gait ($p<0.05$). The length of the lever arm and KAM are presented in Table 2, with the length at the 1st peak of KAM during gait with DI being significantly shorter than the length during level gait without DI ($p<0.05$).

DISCUSSION

The DI maneuver with 2.1 cm shortening of the abdominal circumference successfully decreased the TK angle by 2 degrees in healthy individuals. However, the 1st and 2nd peaks of KAM during gait with DI were not significantly decreased compared with those during level gait in any of the participants. Therefore, the 20 subjects who had successfully decreased TK were analyzed. As a result, the 1st peak of KAM with DI in these subjects was significantly decreased compared with the KAM during level gait. The lever arm length was also significantly shorter than that during the level gait. The main finding in the present study was that the cases with a decreased TK angle due to DI had the ability to decrease KAM due to a shorter lever arm. In other words, the vector of the ground reaction force (the center of gravity) would be close to the knee joint center in the frontal plane. Lateral displacement of the center of gravity to a stance leg is one of the normal strategies for energy-conserving motion[13], and decrease of TK was assumed to induce this normal strategy. Sinaki et al.[14] reported a relationship between balance disorder and kyphosis. A decrease of TK might serve to improve the lateral shift of the center of gravity, decreasing the lever arm of KAM.

DI is used clinically to treat low back pain and to obtain stability of the lumbar spine and pelvis through increased abdominal core muscle activation[15–17], and if was found to increase the thickness of the abdominal core muscles in the forward step posture[18]. In the present study, the thorax was pushed up by the internal abdominal pressure caused by the 2.1 cm shrinkage in abdominal circumference, and this is considered to have induced a decrease of TK. However, nine of the 29 subjects did not show decreased TK due to the simple DI used in the present study. We assumed that

Table 2. First and 2nd peak knee adduction moments and the lever arm length during gait without and with the draw-in maneuver

			Gait ($\times 10^{-3}$)	Gait with DI ($\times 10^{-3}$)
KAM	All subjects	1st peak	58.6 ± 20.4	57.9 ± 28.8
	(n=29)	2nd peak	56.3 ± 17.0	56.8 ± 21.8
	Group 1	1st peak*	57.0 ± 16.3	55.7 ± 24.3
	(n=20)	2nd peak	54.9 ± 12.9	54.6 ± 18.0
Lever arm	Group 1	1st peak*	38.8 ± 11.7	36.4 ± 11.7
length (cm)	(n=20)	2nd peak	39.4 ± 12.4	38.6 ± 12.5

Group 1: 20 subjects who decreased thoracic kyphosis with the draw-in maneuver (DI). *p<0.05. Values are shown as the mean±SD

these nine subjects might not have sufficiently contracted their abdominal muscles when performing DI. The muscle activation in abdominal muscles should be measured and confirmed during DI in a future study.

There are several limitations in the present study. Firstly, a simple verbal instruction for DI was used in the present study, and the abdominal circumference was decreased by roughly the same amount by DI. However, we could not confirm the activation of the abdominal core muscles, and the simple DI used in the present study was not a strict form of DI. Secondly, because the subjects were healthy young adults, we cannot consider the present findings as generalizable to a patient population. Thirdly, although we indicated that decreased TK affected the smooth shift of the center of gravity during gait, we could not directly explain the relationship between TK and the lever arm; moreover, the abdominal core muscle activation might be more related to KAM (lever arm) to induce a smooth shift in center of gravity for stability of the lumbar spine and pelvis.

In light of our main findings, inducing a decrease of TK alone would be better than performing simple DI (2.1 cm shrinkage of abdominal circumference) to decrease KAM in healthy individuals. In the future, this intervention should be conducted for patients with knee OA to clarify the effect in a patient population.

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