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Original Article

Major patterns of plantar flexion resistive torque during the gait cycle in healthy young adults wearing ankle foot orthoses with a plantar flexion stop: a pilot study

Mikio Fujimoto, MD[1)]*, Shota Suzuki, RPT[1)], Hirotaka Kuki, RPT[1)], Minori Masuda, RPT[1)], Keiichi Takei, RPT[1)], Mitsuru Yamamoto, MD, PhD[1)]

[1)] *Department of Rehabilitation, Saitama Medical Center, Saitama Medical University: 1981 Kamoda, Kawagoe 350-8550, Japan*

Abstract. [Purpose] The Gait Judge System measures the plantar flexion resistive torque acting on the angle of the ankle joint, as well as the ankle joint itself, of the ankle-foot orthosis using a 1,000 Hz sampling frequency. This pilot study aimed to determine the characteristics of plantar flexion resistive torque acting on the double Klenzak ankle joint of the ankle-foot orthoses worn by healthy individuals. [Participants and Methods] Participants were eight healthy young adults (3 male, 5 female; mean age, 26.8 years old; mean height, 165 cm.; mean body weight, 56.3 kg). Plantar flexion resistive torques and angles of the ankle joint in gait cycles were measured with the Gait Judge System. Speed of gait was calculated using a ruler attached on the floor and the Gait Judge System video. We classified waveforms according to the existence of second peaks in the gait cycle. The correlations between parameters related to the plantar flexion resistive torque and the speed of gait were evaluated using Pearson's simple correlation analysis. [Results] The plantar flexion resistive torque showed two peaks: the first peak was at the loading response, measured at 17.4 Nm, and the second peak was at the pre-swing phase, measured at 10.9 Nm. However, the second peak was absent in three of the participants. The normalized second peak and the second peak/first peak ratio had a strong, positive correlation with the speed of gait. [Conclusion] The Gait Judge System revealed typical waveforms according to the parameters set in this study.

Key words: Gait analysis, Ankle-foot orthosis, Functional rockers

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INTRODUCTION

Various tools (wearable goniometers, multi-dimensional motion analysis systems, foot plates, and surface electromyograms) have been applied for quantitative gait analysis. Each of these tools is usually selected and combined with other tools based on its respective advantages and disadvantages. Evaluation of the torque acting on the joint is one of the appropriate means to examine joint movement biomechanics. Therefore, it is used in various areas, such as development of orthoses. Measurement of the plantarflexion resistive torque (PFRT) on the ankle joint when wearing an ankle-foot orthosis (AFO) has been devised[1–3)], which has led to the development of a new AFO with dorsiflexion assist[2, 3)].

A device measuring the PFRT acting on the ankle joint of AFO, named the Gait Judge System (GJS) (Fig. 1), has been introduced in Japan[4–6)]. However, few studies exist regarding the GJS[7)], especially in international publications. The GJS automatically measures the PFRTs and angles of the ankle joint with 1,000 Hz sampling frequency. The PFRTs and angles of the ankle joint are displayed graphically, synchronized with the video that is taken during the measurement (Fig. 2). The

*Corresponding author. Mikio Fujimoto (E-mail: m_fujimo@saitama-med.ac.jp)

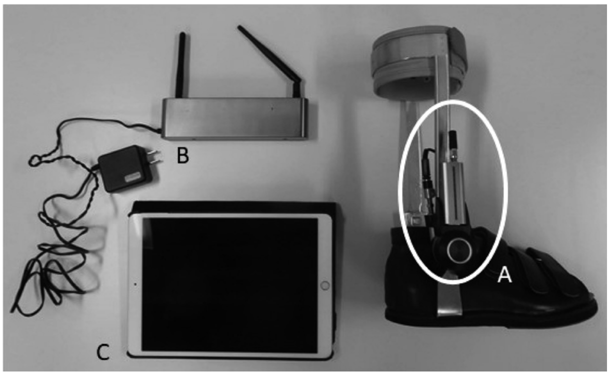

Fig. 1. The construction of the Gait Judge System (GJS) is shown. A: the unit to measure plantarflexion resistive torque (PFRT) and angle of ankle joint that equips transmitter. B: Wi-Fi converter receives signals from A and relays them to the tablet PC. C: The tablet PC equips the software to analyze the measured data.

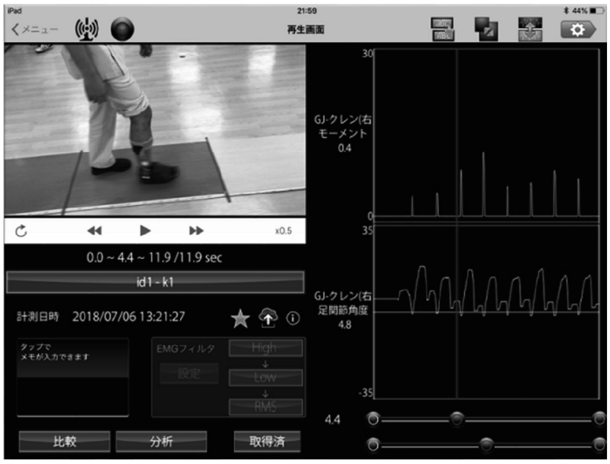

Fig. 2. PFRTs and angles of the ankle joint are displayed graphically synchronized with the video tracked at the measurement.

display of the GJS is convenient and enables intuitive assessment of the three functional rockers[8] that reflects smooth movement of the thigh over the supporting foot.

The GJS is mountable on AFOs with an oil damper resistance, named the Gait Solution[2, 9], or with double Klenzak ankle joints. Previous studies[4–7] have focused on the parameters when using oil damper resistance. These studies demonstrated that PFRT shows two peaks at the loading response (1st peak) and pre-swing phase (2nd peak). The first peak represents the plantarflexion torque generated by ground reaction forces and absorbed by contraction of the tibialis anterior muscle[4, 7]. The 2nd peak is considered to reflect the plantarflexion torque generated by the stretch-shortening cycle[10] of the triceps surae muscle. The mean ranges of the 1st and 2nd peak are reported as 1.3[7] to 1.9[4] Nm and 2.8[7] to 2.9[4] Nm, respectively. Thus, it is deduced that the 2nd peak is higher than the 1st in healthy adults[4]. These reports are based on measurements with AFOs using oil damper resistance, but few reports are available on PFRTs measured with the GJS mounted on double Klenzak ankle joints. This pilot study was aimed to determine the standard patterns of PFRT measured with the GJS mounted on double Klenzak ankle joints as a preliminary step, before its clinical use in patients with hemiplegia.

PARTICIPANTS AND METHODS

Eight healthy young adults (3 males, 5 females; mean ± standard deviation: age, 26.8 ± 2.2 years; height, 165 ± 10.0 cm; body weight, 56.3 ± 9.8 kg) participated in the present study. Individuals with abnormal gait, leather allergy, and metal allergy were excluded.

The examiner chose the most adapted AFO (Fig. 3) from 3 sizes (27 cm, 25.5 cm, and 23.5 cm) with a plantarflexion stop. The orthoses were accurately specified to 2E-width, 1 cm-thick flat sole, 1 cm-height toe spring from the metacarpophalangeal joint, without sole flare in longitudinal nor horizontal direction. AFOs were adjusted to the following conditions. Full dorsiflexion was allowed (Fig. 3E). Plantarflexion was stopped at 0° by the rod attached to the unit of the GJS at the lateral Klenzak ankle joint (Fig. 3F). The unit of the GJS to mount to the AFOs had a built-in angle sensor and a load cell with 1,000 Hz sampling frequency. PFRT was automatically calculated when using the GJS. Additionally, gait speed was calculated using the ruler attached on the floor and the time display of the video on the GJS.

Trains of 5 waveforms (2nd to 6th) of PFRTs output when using the GJS were employed. The waveform peaks were compared to the gait cycle phases, and the kinetic parameters were calculated. Waveforms were classified into 2 groups according to the existence of 2nd peaks in the gait cycle. Kinetic parameters of the classified groups were determined. Correlations between parameters related to PFRT (value of 1st and 2nd peaks of PFRT normalized to body weight, values of 2nd peaks/1st peaks) and speed of gait were evaluated using the Pearson’s simple correlation analysis. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) software (version 11, SPSS, Inc., Chicago, IL, USA). This study was conducted following approval by the ethical committee of the organization to which the researchers belong (The Ethics Committee of Saitama Medical University, No 893). All participants provided written informed consents before being enrolled in the present study.

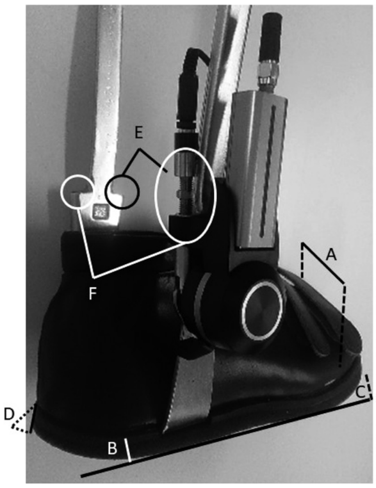

Fig. 3. The AFO used in this study is shown. Orthoses were specified to A: 2E-width, B: 1 cm thick flat sole, C: 1 cm tall toe spring from the metacarpophalangeal joint, D: without sole flare in the longitudinal and horizontal directions. E: Full dorsiflexion was allowed. F: Plantarflexion was stopped at 0 degrees by the rod attached to the GJS at the lateral Klenzak ankle joint.

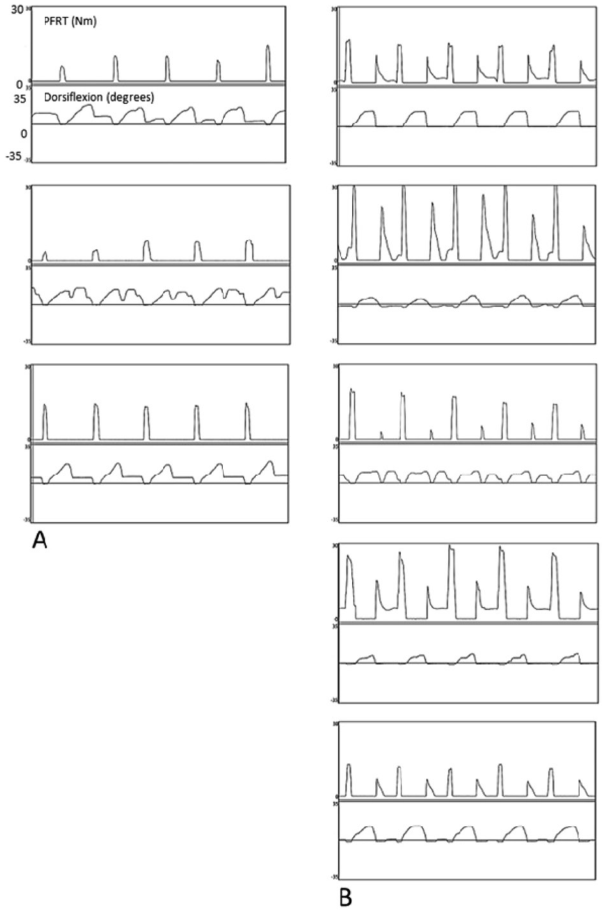

Fig. 4. Waveforms of PFRT output on using GJS are shown. A: Group 1 shows a single peak of PFRT at loading response. B: Group 2 shows two peaks at the loading response and pre-swing phase.

RESULTS

Waveforms of PFRT output obtained using the GJS for all 8 participants are shown in Fig. 4. Similar to the results of previous reports that used oil damper resistance[4, 7)], the PFRT showed two peaks at the loading response (1st peak) and pre-swing phase (2nd peak). The means of the 1st and 2nd peak (if existing) were 17.4 ± 8.5 Nm and 10.9 ± 6.3 Nm, respectively. These values were higher than those seen in previous reports that used oil damper resistance[4, 7)]. However, absence of the 2nd peak was found in 3 participants (group 1) (Fig. 4A). The remaining 5 participants (group 2) had a 2nd peak that was lower than the 1st (Fig. 4B). Positive dorsiflexion of the ankle joint at the swing phase was maintained in all participants of group 1, whereas ankle joints at the swing phase were neutral position in all participants of group 2. The 1st peaks and 2nd peaks of 5 gait cycles were first normalized to body weight and then averaged. The characteristics of the 2 groups are shown in Table 1. The normalized 2nd peak and 2nd peak/1st peak were strongly and positively correlated with speed of gait; the correlation coefficients were 0.75 ($p<0.05$), 0. 306, and 0.73 ($p<0.05$), respectively. However, the normalized 1st peak was not statistically correlated with the speed of gait ($r=0.53$, $p<0.05$).

DISCUSSION

This study revealed that PFRT showed two peaks at the loading response and the pre-swing phase when the GJS is used with double Klenzak ankle joints. This result is similar to that of previous reports using AFO with oil damper resistance. However, the typical waveform of PFRT in the present study differs from that seen in previous studies. Absence of the 2nd peak was found in 3 participants in the present study. Absence of the 2nd peak can be potentially explained by differences in gait strategy reflected by dorsiflexion during the swing phase. The number of samples in this study was insufficient to compare the 2 groups statistically in this pilot study. Nevertheless, the correlation analysis results demonstrated that slower

Table 1. Demographic, physical, and parametric characteristics of participants

	Group 1 (n=3)	Group 2 (n=5)	Total (n=8)	Range
Age (years)	28.0 ± 2.0	26.0 ± 2.1	26.8 ± 2.2	24–30
Height (m)	1.66 ± 0.06	1.64 ± 0.12	1.65 ± 0.10	1.50–1.83
Weight (kg)	56.0 ± 7.2	56.4 ± 11.9	56.3 ± 9.8	40–73
1st peak (Nm)	11.1 ± 3.9	21.2 ± 8.4	17.4 ± 8.5	6.9–32.3
1st peak/weight (m/s^2)	1.95 ± 0.42	2.48 ± 0.63	2.28 ± 0.60	1.53–3.23
2nd peak (Nm)	0	10.9 ± 6.3		4.8–20.8 (if exists)
2nd peak/weight (m/s^2)	0	1.88 ± 0.84		0.88–2.80 (if exists)
2nd peak/1st peak	0	0.50 ± 0.15		0.28–0.65 (if exists)
Speed of gait (m/min)	60.2 ± 3.9	68.0 ± 4.4	65.1 ± 5.6	55.8–75.0

gait speed has a relation to the absence or reduction of the 2nd peak.

The 2nd peak was lower than the 1st peak in all the remaining 5 participants. The cause for the difference in the waveform from that seen in previous reports requires further investigation.

This pilot study as a preliminary step before clinical use focused on gait in healthy adults who wear AFOs; these are actually unnecessary in normal conditions. The gait in the present study substantially differ from normal gait in two aspects: first, plantarflexion of the ankle joint is limited to less than or equal to 0° compared with 15° to 20° of normal gait, and second, the soles with metal shank may block the extension of the metacarpophalangeal joint. Inadequate extension of the metacarpophalangeal joint can influence the timing of the toe-off and of the 2nd peak. These problems are unavoidable as long as the subject wears AFO. However, the original purpose of the GJS was directed to patients who need AFO and not to individuals with normal gait; therefore, we considered that the differences from normal gait caused by wearing AFOs in this study were acceptable, because it was important to obtain the normal standard of PFRT before using it in patients with hemiplegia.

The results of the present study provide a guide to measuring the gait using the GJS. However, one of the limitations of this study was the small sample size; further larger studies are ongoing to clarify the factors affecting PFRT measured with the GJS mounted on double Klenzak ankle joints.

Funding and Conflict of interest

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None of the authors have any conflicts of interest directly relevant to the content of this article.

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