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Original Article

Effects of short-term strength training based on hip flexion angle-torque characteristics using a prototype machine

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Abstract. [Purpose] An unexpected finding was previously observed that hip flexion torque was maximal in the deep flexion position. This study aimed to compares the short-term effects of strength training using a machine with load torque based on the hip flexion angle-torque characteristics identified in our prior study to those of an existing weight stack machine. [Participants and Methods] Seventeen participants were divided into two groups. The conventional training group (CT group) trained with a weight stack resistance machine. The non-conventional training group (non-CT group) trained with a prototype machine based on the hip flexion angle-torque characteristics identified in our previous study. Both groups trained twice weekly for four weeks. Maximum isometric hip flexion torque at 0°, 30°, 60°, 90°, and 105° was measured before and after training, and compared between the groups. [Results] Maximum isometric hip flexion torque showed an interaction between training type and training duration only at 105° of hip flexion, with significantly higher torque observed in the non-CT group. [Conclusion] Short-term training based on the hip flexion angle-torque characteristics identified in our prior study was effective in significantly strengthened muscles in the deep hip flexion range.

Key words: Hip flexion, Joint angle-torque characteristics, Strength training

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INTRODUCTION

Gait ability is essential for carrying out activities of daily living. Gait speed, as an index of gait ability, is widely used to diagnose sarcopenia and frailty[1–3)]. Since stride length and cadence determine gait speed, and the hip flexor muscles influence stride length, training these muscles is crucial for maintaining and improving gait ability. Additionally, the hip flexor muscles play an important role in maintaining a stable posture during various daily activities.

Muscle length and moment arm during joint motion vary with the joint angle, and the variation in torque exerted during joint motion is termed the joint angle-torque characteristic. In strength training, the safety and effectiveness of using a variable load machine according to joint angle-torque characteristics have been reported on[4)], leading to high training efficiency in the knee and elbow joints[5, 6)]. Additionally, previous studies have reported that hip flexion torque decreases as increasing the hip flexion angle increases[7–11)]. However, in those previous studies, the participants either lay on their side or sat on the edge of a bed during hip flexion torque measurement, and the measurements included the effects of postural retention functions. There-

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fore, the actual maximal exerted at each hip joint angle may not have been measured accurately. In our previous research, the isometric maximum hip flexion torque was assessed at different hip angles with the participants in a stable supine position. The maximum isometric hip flexion torque (mean ± SD) for males and females, respectively, was 2.10 ± 0.65 and 1.54 ± 0.51 Nm/kg/m at 0° hip flexion, 2.39 ± 0.77 and 1.75 ± 0.56 Nm/kg/m at 30°, 2.48 ± 0.76 and 1.80 ± 0.57 Nm/kg/m at 60°, 2.41 ± 0.68 and 1.77 ± 0.53 Nm/kg/m at 90°, and 2.64 ± 0.63 and 1.94 ± 0.52 Nm/kg/m at 105°. These results showed that the hip flexion angle-torque was minimal during shallow hip flexion and maximal during deep hip flexion[12)]. Under existing training methods, adjusting the load to accommodate these hip flexion angle-torque characteristics is difficult. Weight stack resistance machines produce isotonic loading torques, making it impossible to generate loading torques that align with the hip flexion angle-torque characteristics. Training with sufficient load torque throughout the entire range of motion of the joint requires a stabile one-legged standing position. When using weights or elastic bands, achieving a load pattern that matches the ideal hip flexion angle-torque characteristics is challenging. This is because, in deep hip flexion, the load torque is attenuated by gravity when training in either a standing or supine position. Constant velocity exercise machines require trainees to maintain set speeds in order to achieve sufficient load. Furthermore, the maximum load cannot be achieved at the end of the range of motion due to the need for acceleration and deceleration phases. Consequently, constant velocity exercise machines may not provide sufficient load torque in joint movements where the peak torque does not occur near the center of the range of motion, such as during hip flexion. In order to overcome these shortcomings, a prototype machine was developed to meet the following three requirements: (1) the ability to generate load torque on the hip flexion angle-torque characteristics; (2) the capability to perform hip flexion exercises in the supine position, suitable for elderly or disabled individuals with limited ability to maintain training posture, and; (3) a simple mechanism with no motor or electronic controls, to minimize material and maintenance costs.

Short-term strength training, designed based on the hip flexion torque characteristics identified in our previous study, was conducted using the prototype machine to evaluate its effectiveness.

PARTICIPANTS AND METHODS

The participants were university students who voluntarily agreed to join the study after receiving a leaflet explaining its purpose and methods, along with a verbal invitation. Individuals were excluded if they met any of the following criteria: (1) a history of osteoarticular or neurological disorders, including prior surgeries, or (2) being in regular strength training targeting the lower extremities or trunk.

Seventeen participants were divided into two groups matched by height, weight, and body mass index (BMI). The first group, referred to as the conventional training group (CT group), trained using a weight stack resistance machine, representing a traditional training method. The second group, referred to as the non-conventional training group (non-CT group), trained using a prototype machine designed based on the hip flexion angle-torque characteristics identified in our research. The non-CT group comprised nine participants (two males), and the CT group eight participants (three males), with ages (mean ± standard deviation) of 20.4 ± 0.5 years for the non-CT group and 21.0 ± 0.5 years, respectively.

This study was conducted in accordance with the Declaration of Helsinki. The purpose and experimental methods were fully explained to the participants, written consent was obtained, and approval was granted by the Ethics Committee of Suzuka University of Medical Science (Approval No. 508).

Previous studies have reported no significant differences in muscle strength between the dominant and non-dominant legs[13–15)]. Therefore, in this study, the right lower limb was chosen as the training target for all participants. Isometric hip flexor strength was measured before and after training at hip flexion angles of 0°, 30°, 60°, 90°, and 105°. A hand-held-dynamometer (HHD) μTasF-1 (Anima Co., Tokyo, Japan) was used for these measurements. To minimize measurement errors, hip flexion torque was calculated and normalized to body weight using a measurement method[12)].

The prototype machine (IH-01, Ihara Kogyo Co., Aichi, Japan) was used while lying on a bed in the supine position. Hip flexion exercises were performed by grasping the bar on the side of the body with both upper limbs to stabilize posture. This mechanism generates load torque through the elastic force of a rotating plate, which rotates during hip flexion and presses against the upper compression spring. The radius of the rotator plate is designed to increase with hip flexion, thereby gradually increasing load torque. The initial torsion spring compression was adjusted based on the participant’s specific load setting. Based on the torque at hip flexion angles of 0° and 105° obtained from our study of hip flexion angle-torque characteristics in healthy adults[12)], the load torque increase for the machine was set at 0.14 Nm/deg.

During training with the weight stack resistance machine (Multi-Hip, Takei Scientific Instruments Co., Niigata, Japan), the participant assumed a one-legged standing position and was instructed to perform hip flexion exercises while grasping the front bar with both upper limbs to stabilize posture. The weight stack resistance machine provides a constant isotonic load: a wire cable is connected to a weight plate, which is pulled through a pulley as the joint moves. Machine plates and 500 g weights were used to adjust the load for each participant.

The training protocol involved concentric contractions from 0° to 105° of hip flexion at an angular velocity of 30°/sec. Training intensity was set at 80% of the maximum isometric torque at 0° hip flexion, as estimated from the 1RM report[16)]. Seventy percent of this value was selected as the starting load torque for the weight stack resistance machine and prototype machine. Each session consisted of three sets of 10 repetitions per set, with a 90-second rest period between sets. Training was conducted twice weekly for four weeks, for a total of eight sessions.

Attribute comparisons between groups were performed using the χ^2 test and the independent two-sample t-test. The two-way analysis of variance (ANOVA) was employed to examine the effects of training on two factors: type of training method and the duration of training. A post hoc analysis was conducted, using the Bonferroni method, when a significant interaction effect was identified. A p-value of 0.05 was considered the threshold of statistical significance. The training effect size was evaluated using Cohen's d, with the following criteria: small (d ≥0.2), medium (d ≥0.5), and large (d ≥0.8). Statistical analyses were performed using SPSS version 26 (IBM, Tokyo, Japan).

RESULTS

Height, weight, and BMI did not differ significantly between the non-CT and CT groups (Table 1). Maximal isometric hip flexion torque increased with training at all measured hip flexion angles in both the non-CT and CT groups (p<0.01). There was an interaction between training machine type and duration at only at 105° of hip flexion only, where training significantly increased torque in the non-CT group (p<0.01) (Table 2). The effect sizes were 1.78, 1.45, 1.48, 1.54, and 1.47 at hip flexion angles of 0°, 30°, 60°, 90°, and 105°, respectively, in the non-CT group, and 1.38, 1.35, 1.26, 1.41, and 0.70 at the same angles in the CT group. The effect size was medium (d=0.7) exclusively for the CT group at 105° of hip flexion, and large (d >0.8) for all other hip flexion angles.

DISCUSSION

This study examined the effectiveness of short-term strength training based on the hip flexion torque characteristics identified in a previous study[12)]. Maximal isometric hip flexion torque increased after training in both the non-CT and the CT groups at all measured hip flexion angles, with a significantly greater increase observed in the non-CT group than in the CT group at 105° of hip flexion. The prototype machine gradually increased the applied torque from 0° to a maximum of 105° of hip flexion. In contrast, the weight stack resistance machine applied isotonic loading torque from the start of the exercise, maintaining a constant load throughout the movement. The prototype machine's machine characteristics optimized the load torque in the deep hip flexion range, which was not achieved with the weight stack resistance machine. Consequently, the prototype machine demonstrated a significant training effect at 105° of hip flexion.

A mathematical model simulation study reported that hip flexion torque does not decrease as the hip flexion angle increases, and remains sustained in the deep flexion range[17)]. The torque generated by all hip flexor muscles, except for the iliopsoas muscle, decreases or becomes minimal as the hip flexion angle increases[18–23)]. In contrast, the torque produced by the iliopsoas muscle increases with greater hip flexion angles, thereby maximizing hip flexion torque in the deep flexion

Table 1. Descriptive data of the participants

	non-CT group (n=9)	CT group (n=8)
Sex (male/female)	2/7	3/5
Height (cm)	159.0 ± 6.9	162.9 ± 8.1
Weight (kg)	49.9 ± 9.9	55.8 ± 1.7
BMI (kg/m^2)	19.5 ± 2.3	21.0 ± 1.7

CT group: conventional training group; non-CT group: non-conventional training group; BMI: body mass index.

Table 2. Maximum isometric hip flexion torque and effect size for the non-CT and CT groups, pre-training and post-training

	non-CT group		CT group	
	Pre	Post	Pre	Post
0° (Nm/kg)	0.97 ± 0.19	1.50 ± 0.38*	0.97 ± 0.34	1.55 ± 0.49*
30° (Nm/kg)	1.11 ± 0.32	1.73 ± 0.52*	1.06 ± 0.23	1.58 ± 0.50*
60° (Nm/kg)	1.10 ± 0.32	1.66 ± 0.44*	1.09 ± 0.26	1.64 ± 0.56*
90° (Nm/kg)	1.21 ± 0.43	1.80 ± 0.33*	1.07 ± 0.30	1.55 ± 0.37*
105° (Nm/kg)	1.38 ± 0.38	1.90 ± 0.32*†	1.29 ± 0.44	1.59 ± 0.43*

*p<0.01, significantly different from Pre; †p<0.01, significantly different from CT group.
The non-CT group used the prototype machine; IH-01 (Ihara Kogyo Co., Aichi, Japan).
The CT group used the weight stack resistance machine; Multi-Hip (Takei Scientific Instruments Co., Niigata, Japan).
CT group: conventional training group; non-CT group: non-conventional training group; 0–105°: hip flexion angle; Pre: pre-training; Post: after four weeks of strength training.

range of the hip joint. Therefore, the increase in maximum isometric flexion torque at 105° of hip flexion observed with the prototype machine in this study is believed to be primarily attributable to the iliopsoas muscle. Collectively, these findings suggest that hip flexor strength training using the prototype machine is more effective than other training methods for individuals experiencing reduced gait and postural function due to iliopsoas muscle weakness.

This study examined the effects of eight short-term training sessions conducted over four weeks. Generally, neural adaptations—such as enhanced motor unit recruitment and increased neural firing frequency—are the primary factors contributing to strength gains during approximately the first four weeks of training. In contrast, long-term training that incorporates full range of motion exercise is essential for achieving significant muscle hypertrophy and further increases in muscle strength[24–26]. Accordingly, future research should investigate whether long-term training of the hip flexor muscle group, based on hip flexion angle-torque characteristics, and using the prototype machine, can enhance the strength and hypertrophic response of the iliopsoas muscle more effectively than other training methods.

Our findings suggest that non-conventional training utilizing the prototype machine, which progressively increases the load torque from 0° hip flexion to a maximum at 105° hip flexion, led to a significant increase in maximum isometric hip flexion torque at 105° compared to conventional training with the weight stack resistance machine. The prototype machine may offer greater benefits for resistance training of the iliopsoas muscle than other training machines. A limitation of this study is that it was a preliminary experiment designed to examine the effects of long-term training on increases in muscle strength and hypertrophy. Since this was a preliminary experiment, the sample size was small, and the participants were also limited to young adults. In future studies on long-term training, it will be important to determine an appropriate sample size and to examine whether long-term strength training with the prototype machine is more effective than other methods in promoting muscle strength gains and hypertrophy. Additionally, it will be necessary to investigate whether training approach is effective across all age groups.

Conflict of interest

This study was conducted in collaboration with Ihara Kogyo Co. The experimental environment was maintained with part of the research grant from Ihara Kogyo, and Ihara Kogyo manufactured the prototype machine. Ihara Kogyo Co. was not involved in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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