



Original Article

Effects of spring-loaded crutches on gastrocnemius activity and upward displacement of the body during gait

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Abstract. [Purpose] This study investigated the effects of spring-loaded crutches on gastrocnemius muscle activity and upper body displacement in the sagittal plane during gait. [Subjects and Methods] The study involved 12 healthy males. All subjects performed crutch gait by using spring-loaded crutches and axillary crutches. During this gait, the gastrocnemius muscle activity was measured using a wireless electromyography system, and upward displacement of the body was measured using a three-dimensional motion analysis system. [Results] The gastrocnemius activity was significantly lower but upward displacement of the body was significantly greater with the spring-loaded crutches than with axillary crutches. [Conclusion] Spring-loaded crutches allow efficient crutch gait and involve less effort from the gastrocnemius muscle.

Key words: Gastrocnemius, Electromyography, Spring-loaded crutch

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INTRODUCTION

Crutches are used to support the gait of individuals with lower extremity injuries¹⁾. However, standard axillary crutches can cause upper extremity injuries²⁾ and involve excessive energy expenditure³⁾. To minimize these negative effects, spring-loaded crutches have been developed⁴⁻⁷⁾. These crutches have a spring at their inferior tip, which stores elastic energy when it comes into contact with the ground and then releases mechanical energy to facilitate upward and forward motion of the body^{4, 7)}. A previous study found a significantly higher peak forward velocity during gait with spring-loaded crutches than with axillary crutches⁶⁾.

Research suggests that minimal displacement of the center of mass with selective muscle control is important for efficient gait⁸⁾. In line with this hypothesis, the activity of the plantar flexor muscles (*e.g.*, gastrocnemius) needs to be minimized to reduce muscle effort and save energy during crutch gait, as these muscles play a primary role in propelling the body forward through push-off during crutch gait. In addition, because excessive displacement of the body in the sagittal plane could lead to an energy-consuming gait pattern⁸⁾, this displacement should be considered together with the change in activity of the plantar flexor muscles when evaluating the mechanical efficiency of a spring-loaded crutch gait. However, to our knowledge, no study has examined the change in upward displacement of the body or electromyographic (EMG) activity of the plantar flexor muscles during spring-loaded crutch gait. Therefore, the aim of the present study is to examine the influence of spring-loaded crutches on the displacement of the body in the sagittal plane and the activity of the gastrocnemius muscle during crutch gait.

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SUBJECTS AND METHODS

This study enrolled 12 healthy males (mean age, 22.1 ± 2.5 years; mean height, 173.2 ± 0.8 cm; mean weight, 66.4 ± 6.8 kg). Individuals were excluded if they had a history of lower extremity surgery or cardiopulmonary disease. Before participation, the subjects signed an informed consent form approved by the Institutional Research Review Committee of Inje University.

To measure EMG activity in the lateral gastrocnemius, the Delsys Trigno Wireless EMG system (Delsys, Boston, USA) was used. The sampling rate was 1,000 Hz, and the signal was bandwidth filtered at 20–450 Hz. All raw data were converted to the root mean square values. Before the EMG electrodes were attached, the skin was swabbed with alcohol-soaked cotton to reduce resistance. An EMG electrode was placed just distal to the knee joint line and 2 cm lateral to the midline, in the direction of the muscle fibers on the dominant leg⁹. The maximum voluntary isometric contraction (MVIC) was measured to normalize the EMG data. To determine the MVIC of the gastrocnemius, the participants stood on one leg with weight-bearing on the dominant leg, and then maximum plantar flexion of the weight-bearing leg was performed for 6 s¹⁰. Only two MVIC trials were performed to minimize muscle fatigue caused by repeated maximum muscle contraction trials. The mean value of the middle 3 s of both trials was calculated to determine the %MVIC of the gastrocnemius.

A three-dimensional motion analysis system with eight MX-T10 cameras (Vicon Motion Systems, Oxford, UK) was used to measure the displacement of the body during crutch gait. A reflective marker was placed on the second sacral vertebra because the center of mass is located slightly anterior to the second sacral vertebra¹¹.

In this study, all participants performed five cycles from a step to a three-point crutch gait using standard axillary crutches and spring-loaded crutches, in a randomized order. One crutch gait cycle was defined a heel strike to the next heel strike. The crutch length was optimized to the height of the participant before the experiment¹². To perform the step to three-point crutch gait, the participant stood with his body weight on the dominant leg. He was instructed to place the crutches in front of his body and then move the foot of the weight-bearing leg to the midpoint between the tips of both crutches while advancing the body¹². The crutch gait trials were repeated three times each for standard axillary crutches and spring-loaded crutches, with a 3-min rest between conditions. Before the trials, all participants practiced crutch gait for 20 min to familiarize themselves with both crutch types.

The mean values of EMG data were calculated during the third crutch gait cycle, and the displacement of the body in the sagittal plane was determined as the peak-to-peak difference in the second sacral marker in the sagittal plane during the third crutch gait cycle. The mean value of the three trials for each condition was used for data analysis. A paired t-test was used to compare the EMG activity of the gastrocnemius and the amount of upward displacement of the body between the crutch types. The data were analyzed using PASW Statistics (ver. 18.0; SPSS, Chicago, IL, USA), and the level of significance was set at 0.05.

RESULTS

The gastrocnemius EMG activity was significantly lower with the spring-loaded crutches than with the axillary crutches (%MVIC= 42.4 ± 26.3 vs. 49.9 ± 24.6 , $p=0.020$), while upward displacement of the body was significantly greater when performing crutch gait with the spring-loaded crutches (71.9 ± 24.1 vs. 61.3 ± 17.9 mm, $p=0.008$).

DISCUSSION

Our findings demonstrate that compared to standard crutches, spring-loaded crutches minimize the effort exerted by the plantar flexor muscles and yet enables greater upward displacement of the body during crutch gait. The results showed that gastrocnemius EMG activity was lower when spring-loaded crutches were used than when axillary crutches were used ($p=0.020$). During normal gait, push-off is primarily performed by the plantar flexor muscles⁸. During crutch gait, however, it is performed using the force generated by the crutches, which can lead to injuries related to upper extremity overuse². Therefore, efficient ankle push-off is required to prevent these injuries during crutch gait. The elastic energy stored when using spring-loaded crutches may aid efficient ankle push-off. Spring-loaded crutches store elastic energy and transform it into mechanical energy, leading to efficient body advancement during gait^{4, 7}. Therefore, we believe that the elastic energy generated by the spring-loaded crutches assists efficient push-off, which consequently leads to decreased gastrocnemius muscle activity during gait with these as compared to axillary crutches.

Despite the decreased gastrocnemius EMG activity with spring-loaded crutches, the upward displacement of the body was significantly greater with these crutches than with axillary crutches ($p=0.008$). Although this increases mechanical energy consumption during normal gait⁸, the findings of the present study showed that the EMG activity of the gastrocnemius, the primary muscle for upward body displacement, was in fact significantly decreased during spring-loaded crutch gait. The increased upward body displacement may be attributed to the propulsion force resulting from the elastic energy generated by the spring-loaded crutches, and not to increased mechanical energy consumption. The reported greater mechanical efficiency during gait with spring-loaded crutches compared to axillary crutches supports this inference⁶.

The present study has some limitations. First, the sample size was too small for the findings to be generalizable. Second, the change in the EMG activity of the upper extremity muscles contributing to propulsion (*e.g.*, the latissimus dorsi) was not measured. Future research needs to identify the influence of spring-loaded crutches on upper extremity muscle activity. In addition, actual energy expenditure was not calculated in the present study.

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