# Computer simulation model of FES assisted swing-through gait

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## Abstract

***Objectives: To evaluate a kinematics of swing-through gait with free-knnes in non-disabled individuals and to simulate FES assisted swing-through gait.***

***Methods: Twelve non-disabled adult males participated in this study. Joint angles and ground reaction forces were investigated during the swing-through gait with Lofstland crutches. Dynamic muscloskeletal model was developed to simulate the FES assisted swing-through gait in complete paraplegics with free-knees.***

***Results: The mean maximum flexion and extension angle of the hip joint were 42.6 ± 10.5 degrees (Mean ± SD) and -11.7 ± 8.9 degrees. The mean maximum flexion and extension angle of the knee joint were 44.8 ± 9.0 degrees and -12.6 ± 7.5 degrees. The mean maximum flexion and extension angle of the ankle joint were 6.7 ± 10.5 degrees and 11.1 ± 13.7 degrees. The dynamic muscloskeletal model was successfully controlled.***

***Conclusion: The kinematic data were applied in the simulation models for the swing-through gait in complete paraplegics with free-knees.***

## 1. INTRODUCTION

Swing-through gait is a method of providing paraplegic patients a faster means of mobility[1-3]. It is a fast and effective gait pattern for paralyzed patients who are able to perform it with the use of leg braces and crutches. For the complete paraplegic patient who has no control at and distal to the hip, the swing-through crutch gait is achieved by using long leg braces like a knee-ankle-foot-orthosis (KAFOs) for the stabilization of knee joints during the stance phase[2]. The patient using long leg braces needs to maintain extended elbow and shoulder depression to lift the body from the floor during the swing phase of the legs. The energy cost of the swing-through crutch gait using long leg braces is prohibitive, and many patients abandon this method in favour of the wheelchair[1].

Another approach to swing-through gait in complete paraplegics is by Functional Electrical Stimulation (FES). Heller and colleagues first reported the clinical study of FES assisted swing-through gait with free-knees, and concluded that it is shown to be a potentially useful mode of FES gait[3].

The purpose of this study was to evaluate a kinematics of swing-through gait with free-knnes in non-disabled individuals and to simulate FES assisted swing-through gait .

## 2. METHODS

### 2. 1 Subjects

Twelve non-disabled adult males (age range 20 to 37yrs; mean, 26yrs) volunteered for this study. The mean height of the subjects was 173cm (between 157 and 183cm). The mean weight was 63.9kg (between 54.3 and 75.0kg). The subjects had no previous disease or injuries to their musculoskeletal systems. All subjects provided informed consent to participate in this study.

### 2.2 Swing-through gait analysis

The motion analysis data was obtained during the swing-through Lofstland crutches gait without brace.
Kinematic data of the swing-through gait was recorded by using computer video-based

integrated three-dimensional system for human motion analysis (Peak Motus® Motion Measurement Systems, Peak Performance Technologies, Inc., USA). Prior to data acquisition, reflective markers were placed on fifteen anatomical locations on the subjects as follows: bilateral positions of the shoulder, elbow, hip, knee, ankle, and foot. An additional marker was placed on the neck (C7 level) and the bilateral Lofstland crutch tips.
The ground reaction forces of the foot and Lofstland crutch during locomotion were monitored by three Kistler force platfrms (Kistler force plate 9281B, Kistler Instruments AG, Switzerland)[3].

### 2.3 Computer simulation model of swing-through gait

We developed a skeletal dynamics model for swing-through gait consisting of six linked rigid bodies (Figure 1). Muscle dynamics model by Hase and Yamazaki was used to compute all musculotendon forces[4]. The dynamic muscloskeletal model was controlled by running MSC. Visual Nastran 4D (MRI Systems, Inc., Tokyo, Japan) and MATLAB® (The MathWorks, Inc., USA) circuit.

## 3. RESULTS

### 3.1 Kinematic data of swing-through gait

The mean maximum flexion and extension angle of the hip joint were 42.6 ± 10.5 degrees (Mean ± SD) and -11.7 ± 8.9 degrees. The mean maximum flexion and extension angle of the knee joint were 44.8 ± 9.0 degrees and -12.6 ± 7.5 degrees. The mean maximum flexion and extension angle of the ankle joint were 6.7 ± 10.5 degrees and 11.1 ± 13.7 degrees. Figure 2 shows the representative stick figures and profile of joint angles of the hip and knee joint during one gait cycle of the swing-through gait.

### 3.2 Computer simulation

The dynamic muscloskeletal model was successfully controlled with a MATLAB® - MSC. Visual Nastran 4D circuit. The FES assisted swing-through gait in complete paraplegics with free-knees could be reconstructed in the computer simulation.

## 4. DISCUSSION AND CONCLUSIONS

In this study, kinematic data were corrected during swing-through gait with free-knees in non-disabled persons by using Lofesland crutches. The data obtained from this study were applied in simulation models, and the dynamic muscloskeletal model showed the FES assisted swing-through gait in complete paraplegics with free-knees.

In some cases FES has been used to maintain the knees locked in extension throughout the gait cycle. This method emulates the role of long leg braces and is still expensive in energy cost. However, FES assisted swing-through gait with free knee is adequate for reducing this energy cost.

Based on the computer simulation results, there is a potential to be access the reconstruction of FES assisted swing-through gait with free-knees in paraplegic patients. Our future plans contain the development of the stimulation strategy for the successful FES assisted swing-through gait.

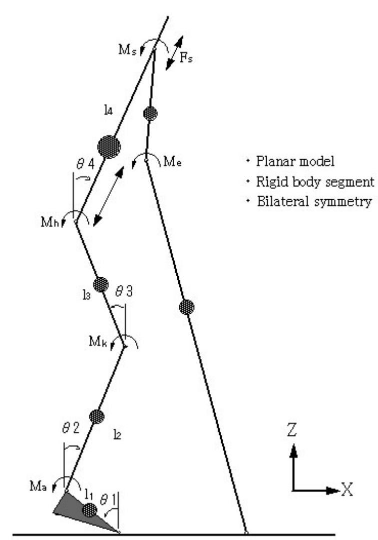


**Figure 1.** Skeletal dynamics model for swing-through gait.

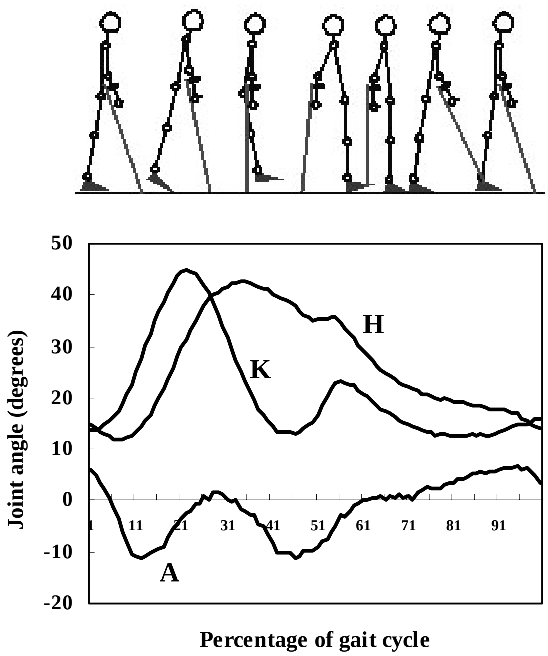


**Figure 2.** Mean joint angular displacement at the hip (H), knee (K) and ankle (A) normalized for a complete gait cycle (0-100%).

## References

[1] Noreau L, Richards CL, Comeau F, Tardif D. Biomechanical analysis of swing-through gait in paraplegic and disabled individuals. *J. Biomechanics* 28: 689-700, 1995.

[2] Thys H, Willems PA, Saels P. Energy cost, Mechanical work and muscular efficiency in swing-through gait with elbow crutches. *J. Biomechanics* 29: 1473-1482, 1996.

[3] Heller BW, Granat MH, Andrews BJ. Swing-through gait with free-knees produced by surface functional electrical stimulation. *Paraplegia* 34: 8-15, 1996

[4] Hase K, Yamazaki N. Development of three dimensional musculoskeletal model for various motion analyses. *Trans Jpn Soc Mecl Eng* 61: 4417-4422, 1995.