INTRODUCTION

Running is one of the basic human movements, and running fast is one of the most important abilities in various sports. 100 m sprint of athletics is said to be an event to compete human ability of maximum running velocity. Biomechanical studies on the sprint running have been done from various viewpoints. Although changes in the velocity, stride length and stride frequency during 100 m sprint race have been investigated, there is little information of change in running motion itself and kinetics of the lower limb joints with the increase in the distance of 100 m. Therefore, it is useful to investigate the relationship between changes in kinetics of the lower limb joints and the running velocity during 100 m sprint race for obtaining insights into sprint technique and to training to improve the performance of 100 m sprint race. The purpose of this study was to investigate change in kinetics of the lower limb joints with the progression of 100 m sprint running.

METHODS

Nine male sprinters participated in this study (height: 1.72±0.03 m, body mass: 64.9±3.8 kg, 100 m personal best record: 10.83±0.36 s). Subjects who were sprinting 100 m with a maximum effort were videotaped at every 10 m from the start to the 90 m mark with five high-speed cameras (250 Hz) and five normal VTR cameras (60 Hz). Two-dimensional coordinates of the body landmarks were obtained by digitizing VTR images over at least one cycle. In addition, one cycle of the running motion was divided into three phases: the support, early recovery and late recovery, as shown in Figure 1.

Performance descriptors such as stride length, stride frequency, were calculated from the two dimensional coordinates data.

Since no force platform was used in the present study, ground reaction forces were estimated from the product of the body mass and the acceleration of the center of gravity. Joint torque, torque power and work done at the lower limb joints were calculated with an inverse dynamics approach. These variables were compared between adjacent marks to identify the changes with the progression of the distance by using Wilcoxon Signed-Rank Test, set significant level at 5%.

RESULTS

Figure 2 shows changes in the running velocity, stride length and stride frequency in the 100 m sprint. The running velocity significantly increased from the 10 m to 40 m marks and significantly decreased between the 70 m to 90 m marks. The stride length increased from the 10 m to 30 m marks. The stride frequency significantly increased from the start to the 10 m mark, and decreased at the 70 m mark. Based on the changes in the performance descriptors, 100 m could be divided into four stages: first acceleration, second acceleration, max velocity and deceleration, as shown in Figure 2.

Figure 3 shows changes in the positive and negative works done by the joint torque of the lower limb during 100 m sprint. In all marks, the amount of positive work was large in descending order of the hip, ankle, knee, and the negative work was large in descending order of knee, hip and ankle. In the hip joint, the positive work significantly increased from 40 m to 50 m mark, and decreased at the 30, 70 m marks. In the knee joint, the positive work significantly increased from 40 m to 50 m mark, and decreased at the 20, 70 m marks. The negative work significantly increased at the 20, 50 m marks and decreased from 60 m to 70 m mark. In the ankle joint, the positive and negative works significantly increased from 40 m to 50 m mark, and decreased from 60 m to 70 m mark.
Figure 2: Changes in the running velocity, stride length and stride frequency in the 100 m sprint.

Figure 4 shows a summary the work done by the joint torque of the hip, knee and ankle joints during various stages of 100 m sprint. The arrows in the figure show significant difference in works from the previous mark, the arrow direction shows that of torques, and white / black arrows indicate positive / negative works. The character I / D indicates significant increase / decrease from the previous mark.

Compared 10 m mark and 20 m mark, the positive work of the hip and the negative work of the knee in the early recovery phase, and the negative work of the hip and knee in the late recovery phase significantly increased. Compared 20 m mark and 30 m mark, the negative work of the knee extensor in the early recovery phase significantly decreased. Compared 30 m mark and 40 m mark, the positive work of the hip and negative work of the knee in the early recovery phase significantly decreased. Compared 40 m mark and 50 m mark, the positive work of the hip and the negative work of the knee in the early recovery phase, and the positive work of the hip and the negative work of the knee in the late recovery phase significantly increased. Compared 60 m mark and 70 m mark, the positive work of the hip and the negative work of the knee in the early recovery phase, and the positive work of the hip and the negative work of the knee in the late recovery phase significantly decreased.

**DISCUSSION**

In the first acceleration stage, 0 ~ 30 m, the stride length continued increasing, and the stride frequency increased from the start to the 10 m mark. Moreover, the positive work of the hip and the negative work of the knee in the early recovery phase, and the negative work of the hip and knee in the late recovery phase significantly increased.
It is inferred that the increase in the positive work of the hip flexors contributed to pulling the recovery leg forward in the early recovery phase. In addition, the eccentric contraction of the hip extensors and knee flexors might inhibit the flexion of the hip joint and the extension of the knee joint in the late recovery phase. These results indicate that the increase in the work of the hip and knee joints in the recovery phase will closely relate to the increase in the running velocity in this stage.

In the second acceleration stage, 30 ~ 50 m, the positive work of the hip flexors and the negative work of the knee extensors in the early recovery phase significantly decreased. The result indicates that the decrease in the work of these joints may be one of a limiting factors to increase speed and / or to save energy and maintain the running velocity in the latter stage of 100 m sprint.

In the max velocity stage, 50 ~ 70 m, the positive work of the hip flexors and the negative work of the knee extensors in the early recovery phase, and the positive work of the hip extensors and the negative work of the knee flexors in the late recovery phase significantly increased at 50 m. These results indicate that the increase in the work would contribute to maintaining the high running velocity in this stage. Especially, it is thought that the positive work of the hip flexors in the early recovery phase and the negative work of the hip flexors in the late recovery phase are important in this stage.

In the deceleration stage, 70 ~ 100 m, the positive work of the hip flexors in the early recovery phase, and the positive work of the hip extensors and the negative work of the knee flexors in the late recovery phase significantly decreased at 70 m mark. Ae et al. (1986) described that the positive work of the hip and negative work of the knee flexors in the recovery phase would be a limiting factor of the stride length and stride frequency. With considering the change in running velocity, the decrease in the work done by the hip flexors in the early recovery phase and the work done by the knee flexors in the late recovery phase would be due to fatigue and result in the decrease in the running velocity and stride frequency in this stage.

The negative work of the knee flexors in the late recovery phase continued increasing from the start to the max velocity phase and then significantly decreased in the 70 m mark where the deceleration of running velocity was observed. This result reveals that the negative work of the knee flexors may be a limiting factor to increase and maintain the running velocity.

In conclusion, the negative work of the knee flexors, knee extensors and knee flexors in the late recovery phase seemed to relate to the acceleration of running velocity of 100 m sprint the positive works of the hip flexors in the early recovery phase and of the hip extensors and the negative work of the knee flexors in the late recovery phase can be a limiting factor of both maximum running velocity and speed endurance.

REFERENCES