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Joint Torque Evaluation of Lower Limbs in Bicycle Pedaling

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Abstract

In this paper, joint torque powers of lower limbs in bicycle pedaling were investigated numerically. An approximation method of relationship between the angle of the ankle and normal force in the rotation direction of a bicycle crank while pedaling was investigated

To calculate the joint torque power of lower limbs, a free body diagram of the motion of the lower limbs was formulated in the 2-dimensional plane. We assumed that the movements of the greater trochanters while pedaling were too small to consider. Also, bicycle shoes were supposed to be fixed to binding pedals. The free body diagram of one leg has two degrees of freedom, the crank angle and the ankle angle, when it is assumed that the greater trochanters are relatively motionless during bicycle pedaling. In previous research, the ankle angle during bicycle pedaling was obtained directly from image analysis using high-speed cameras each time the pedaling output or cadence changes. However, the relationship proposed here does not require image analysis software with high-speed cameras each time the pedaling output or cadence changes : All positions of the lower limb segments, the joint torques and the joint torque powers were calculated from the lower-limb model.

The analytical system for bicycle pedaling comprised cleat-shape biaxial load cells and a program to evaluate pedaling effectiveness, joint torque and joint torque power. The plastic cleats between shoe-sole and binding pedal were replaced with biaxial load cells, which measured the biaxial-forces of right and left legs independently. Evaluations of the joint torques of the lower limbs were conducted with five male subjects to demonstrate the applicability of the proposed method.

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Keywords: Joint torque; Joint torque power; Cycling

1. Introduction

The purpose of this research was to evaluate the joint torque power of lower limbs using our bicycle pedaling system. This system employs a newly proposed relationship between ankle angle and normal force in the rotation direction of a bicycle crank. Today, many cyclists train with power meters. Power meters are able to measure torque applied to the crank. The torque is measured by multiplying the bicycle driving force by the length of the crank. Since not all of the human leg power is converted to driving forces, cyclists must apply leg power to the pedals in an optimum direction in order to reduce the loss of power. Pedaling force can be decomposed into tangential and normal components of crank rotation. The tangential component is effective as a driving force while the normal component clarifies the relationship between human leg power and bicycle driving force.

In addition, joint torque data for each joint of the lower limbs (ankle, knee and hip) could give us information about muscle fatigue. Joint torque power measured by multiplying the joint torque by the joint angular velocity allows a detailed evaluation of muscle activity. Wangerin et al. (2007) evaluated the joint torque in pedaling based on an inverse dynamics calculation. Purdue et al. applied an evaluation system for muscle activity and joint torque using a musculoskeletal model. These systems required image-analysis software in combination with a high-speed camera to determine ankle angle, making the evaluation of pedaling efficiency during an actual competition difficult.

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In this research, a relationship between the ankle angle and normal force of bicycle crank was applied to calculate positions of lower limb joints.. This relationship does not require the use of any image-analysis software with the high-speed camera for each subject. The joint torque of the lower limbs while bicycle pedaling was calculated using the proposed relationship.

2. Construction of evaluation system

2.1. Modeling lower-limb motion

Modeling of lower-limb motion was conducted for the following two reasons. First, it allowed the measured forces to be converted into effective and non-effective forces in order to evaluate pedaling technique. This conversion was based on crank and pedal rotation. Second, it provided kinematic data for the lower limb motion while pedaling. By obtaining kinematic data, joint torque and joint torque power can be calculated.

The lower-limb model was formulated with a link mechanism. Crank rotation was calculated using a magnetic transducer. Lower limb behavior was observed from beside the bicycle, and the positions of the bottom of the bracket and of the greater trochanter were considered fixed points. Moreover, the length of the crank and of each element of the lower limb were considered constant. Thus, if ankle angle has been determined, lower limb behavior depends on crank rotation. Therefore, ankle angle was calculated using the proposed relationship. The proposed relationship was between the ankle angle and normal force in the rotation direction of the bicycle crank (Figure 1). This figure shows that the relationship between ankle angle and normal force in the rotation direction of the bicycle crank was not significantly affected by pedaling output: We applied following two linear equation to relationship between ankle angle and normal force of bicycle crank to investigate the effect of ankle angle to joint torque.

$$\gamma = \gamma_1 f_n + \gamma_2 \tag{1}$$

Where γ is the ankle angle, f_n is the normal force, and γ_1 and γ_2 are constant parameters for each subject. Two variables used in the approximation method were determined by using relationship between the ankle angle and normal force in the rotation direction of a bicycle crank. Also, the length of each element of the lower limb, the length of the crank and the position of the greater trochanter were given as constant parameters. In this research, analysis of joint torque power determined by two linear function was performed.

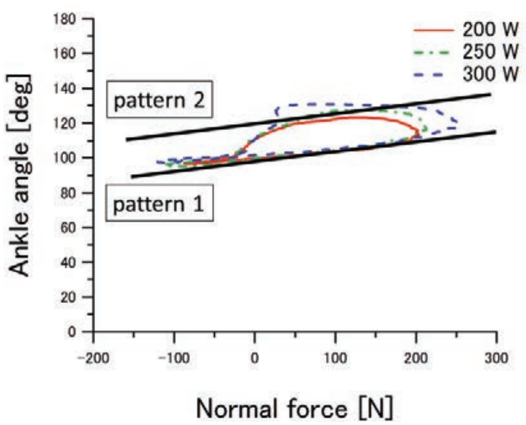

Fig. 1 Relationship between ankle angle and normal force (Subject E)

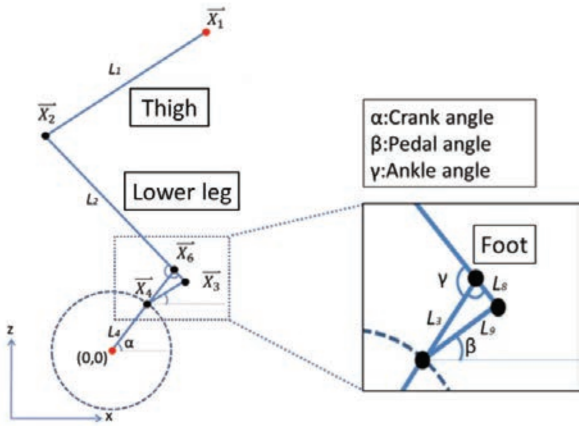

Fig. 2 Link mechanism of lower limb

2.2. Calculation method for joint torque and joint torque power

Joint torque is the resistive force acting on the body due to the influence of external forces. Evaluation of joint torque contributes to injury prevention and to the construction of training programs. To calculate joint torque, a free body diagram of the lower limb, based on Ae and Fujii (2002), was applied (Figure 3). The free body diagram separates the lower limb into three segments (thigh, lower leg and foot). Calculations of motion for translation and motion for rotation were made with the following equations:

$$m_k \vec{\ddot{x}}_k = \vec{f}_{k,P} - \vec{f}_{k,D} + m_k \vec{g} \tag{2}$$