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Coupling Characteristics of Anterior Cruciate Ligament and Gait Analysis on Anterior Instability of Knee[1]

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Abstract: Knee is the largest and most complicated joint in the human body. Since in humans the knee supports nearly the whole weight of the body, it is the joint most vulnerable to acute injury. Normal knee joint movements are accomplished via an intricate balance between passive ligamentous and active muscular components to maintain knee stability and prevent injury. The anterior cruciate ligament (ACL) is a critical passive component to normal knee function which acts to resist anterior rotatory motion of the tibia relative to the femur. The objective of this study is to investigate the coupling characteristic of the ACL, also try to search the kinematics and kinetic coupling characteristic make the quadriceps asymmetry after the ACL injured. Meanwhile this paper mainly presents some lower extremity data of the patients who had the anterior instability on the knee due to the ACL injury based on a infrared reflective marker system using stereophotogrammetry techniques. The compensatory mechanism and the biological coupling characteristic are analyzed in the paper. The results of this paper provide fundamental information on further study of kinematics and segmental coupling. The results of time-distance parameters indicate that the efficiency of walking is lower to some extent by decreased gait frequency and speed and prolonged

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gait circle that lead to unsteadiness of knee after injury. The kinematics data results demonstrate that the joint angle of extremity have adaptable changes produced by nervomuscular control system after injury. The kinemics data show that the other joints of affected extremity and joints of unaffected extremity both have adaptable changes, which is compensation profiting knee stability after injury.

Keywords: biological coupling; kinematic coupling; compensatory mechanism

1. INTRODUCTION

The knee (QU &YU, 2003) joint joins the thigh with the leg and consists of two articulations: one between the femur and tibia, and one between the femur and patella. It is the largest and most complicated joint in the human body. The knee is a mobile trocho-ginglymus, which permits flexion and extension as well as a slight medial and lateral rotation. So in this study only the sagittal data are presented. Since in humans the knee supports nearly the whole weight of the body, it is the joint most vulnerable to acute injury. Normal knee joint movements are accomplished via an intricate balance between passive ligamentous and active muscular components to maintain knee stability and prevent injury. The anterior cruciate ligament (Webster et al., 2005; Torry et al., 2004; Georgoulis, 2003; Hooper et al., 2001) (ACL) is a critical passive component to normal knee function which acts to resist anterior rotatory motion of the tibia relative to the femur. Therefore, the ACl injuries are common, especially among the athletes.

Researchers studying bionics rarely focused on the injured human. However, after ACL injured (Ferber et al., 2003), both quadriceps of the patient were asymmetry. The affected limb's muscular atrophy was obvious, but the gait looked no different from the normals'. Therefore, to study on the gait can reveal the synergy (SUN & DAI, 2007; LU, 2004) and kinematic coupling mechanism of the adaptive ability on ACL patients.

The objective of this study is to investigate the coupling characteristic (REN, 2009; TONG et al., 2005; Peter & Richard, 2007) of the ACL and kinematic coupling of the low extremity , also try to search the changes of the kinematic coupling characteristic after the ACL injured. The long term aim is to establish the database of the abnormal gait and hence to improve our understanding of the locomotor functions (ZHAO et al., 2008) of the compensate strategies. Meanwhile this paper mainly presents some lower extremity data of the patients who had the anterior instability on the knee due to the ACL injury based on a infrared reflective marker system using stereophotogrammetry (REN et al., 2008; Cappozzo et al., 2005) techniques. From one typical gait (REN et al., 2005) pattern which has the special function, by analysising the compensatory mechanism and searching the biological coupling (REN &LIANG, 2009) characteristic. The result of this paper provides fundamental information on further study of kinematics and segmental coupling.

2. THE COUPLING CHARACTERISTICS OF THE ACL

ACL acts as a main restraint of anterior translation of the tibia (Odensten & Gillquist, 1985). Ligament is highly innervated, more than 1,5% of its volume is constituted by nerve endings,4 types of receptors are detected inside the ACL,mainly the Ruffini receptors and Golgi tendon organs could be the sensor for the loads, and avoid injuries. Being the receptors for stimuli, it could correspond for the muscles contractions, and support the stability indirectly by preventing the tibia forward to prevent the injuries (Courtney et al., 2005). In the point of histology, the ACL which has the similar characteristics as cartilage is different from the ligament in the traditional ideas. Due to the different environment, the ACL adapts the systematization for it. This coupling characteristics supply the anti-shock ability during the long-time movement. The normal load for the ACL is from 500N to 700N, the losing effect intensity of entire ACL is about 1700N along the tibia axes, and 2400N along the ACL axes. These loads outclass the weight of the human, so the

ACL could protect the knee joint. Even facing the shock, the ACL could protect the knee joint from the injury in a certain extent.

3. METHODS

Two groups were compared: 30 anterior cruciate ligament deficiency patients (mean 14 months after injury), and 30 matched controls. A 3-dimensional VICON motion analysis and KISTLER force plate system was used to determine kinematics and kinetics of the lower limb during comfortable-speed walking. The testing protocol was the same for both groups. The subjects were asked to walk at a self-selected pace on a10-meter walkway. All gait mean variables were calculated by averaging 12 strides from 6 trials or walks. In each trial, two consecutive strides from each side were recorded. 12 strides were considered an adequate sample. All patients with ACL deficient had resumed activities of daily living. The variables examined in the present study were the lower limb kinematic and kinetic parameters in special phase as well as time-distance parameters during gait. One-way analyses of variance were performed on the subject means on the listed parameters.

4. RESULTS AND ANALYSIS

The experiment data for all subjects are analyzed. A general trend of the gait changes hold for all subjects, yet the patterns of knee moments varies considerably among the control group (CON) affected limb group (AL) and unaffected limb group (UL). In this paper, the mean results are presented, with the purpose to show the compensate strategies after ACL injuries.

4.1 Time-Distance Data

Table 1: Time-Distance index （Affected limb and Unaffected limb）

	Affected limb（AL）	Unaffected limb（UL）	Indifference
Pace（pace/min）	111.2±4.4	111.5±4.7	111.2±4.4
Gait cycle（%）	1.08±0.04	1.08±0.05	1.08±0.04
Stance（%）	58.1±1.7	59.5±2.8	58.9±1.7
Pace width（m）	0.69±0.07	0.69±0.06	0.69±0.07
Speed（m/s）	1.29±0.13	1.29±0.14	1.29±0.13

Table 2: Time-Distance index（ACLD and CON）

	ACLD	CON
Pace（pace/min）	111.2±4.4*	116.90±5.4
Gait cycle（%）	1.08±0.04*	1.03±0.1
Stance（%）	58.9±1.7	58.3±2.1
Pace width（m）	0.69±0.07	0.69±0.05
Speed（m/s）	1.29±0.13*	1.35±0.12

The results of time-distance parameters indicates that there was no lameness due to dissymmetry of affected and uninjured side limb on time-distance parameters after ACL injury, but comparing to the CON, the efficiency of walking is lower to some extent by decreased gait frequency and speed and prolonged gait circle that lead to complaint and unsteadiness of knee after injury.

4.2 Kinematics Data

To investigate the kinematic coupling of the lower extremity movement, the knee flexion-extension angles, the ankle plantarflexion-dorsiflexion angles and hip flexion-extension are shown in the Fig.1, Fig 2, Fig 3. The sagittal data illustrates very strong coupling of the low extremity when the gait changed after the ACL fractured. The kinematics results demonstrate that the joint angle of extremity has adaptable changes produced by nervomuscular control system after injury.

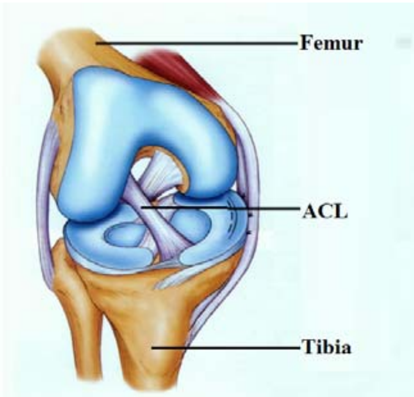

Fig. 1: The Structure of the Knee (Brian & Jon, 2008)

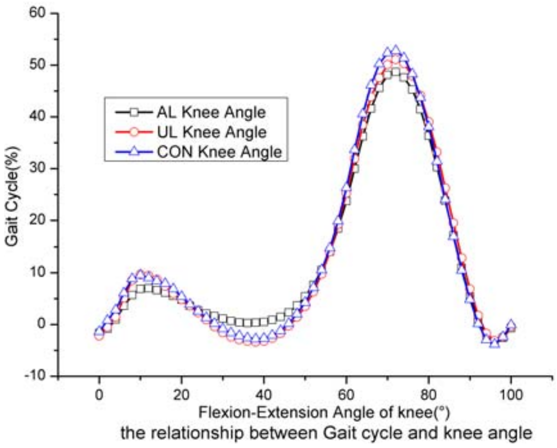

Fig. 2: Flexion-Extension Angle of Knee

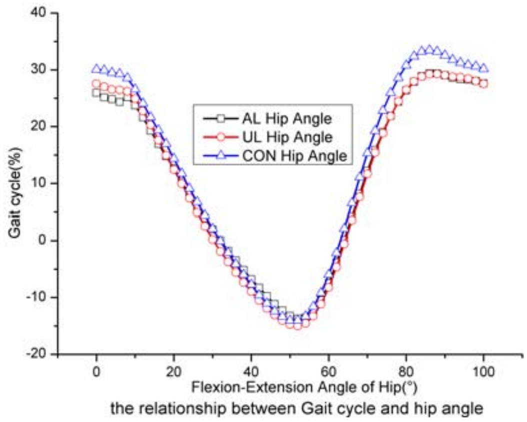

Fig. 3: Flexion-Extension Angle of Hip

These curves reveal no significant differences between the three groups, except maximum extension of the knee during the gait cycle. Specifically, a significant difference is found in maximum extension angle in the AL group when compared with the UL and the control group. The ankle AL and UL position curve generally parallel the CON. However, the AL and UL position are significantly more plantarflexed than CON during the whole gait.

4.3 Kinemics Data

The kinemics in Fig 4, Fig.5, Fig 6 show that both joints of affected and unaffected extremities have adaptable changes, which is compensation profiting knee stability after injury.

All of the moment curves on knee differ markedly from one to another. The curves of Knee UL is significantly less than Knee AL reveals that UL compensated for the AL amounts of moment during swing.

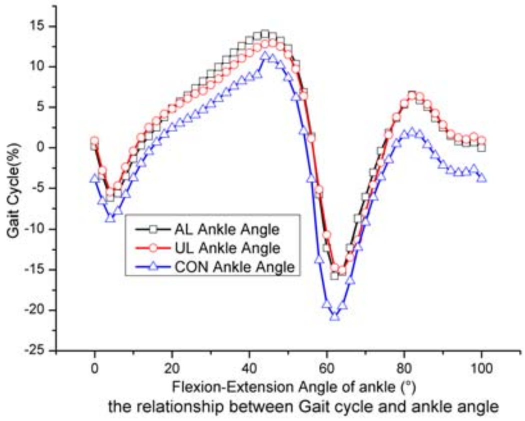

Fig. 4: Plantar flexion-Dorsiflexion Angle of Knee

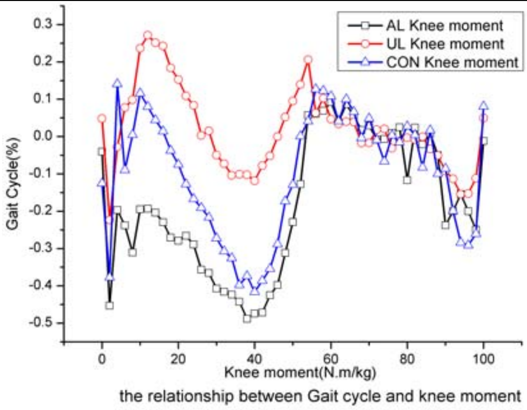

Fig. 5: Knee Moment

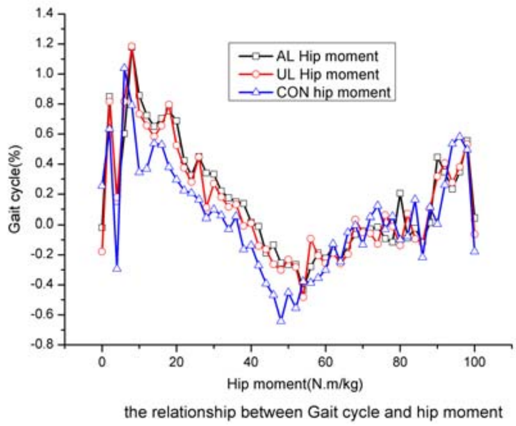

Fig.6: Hip Moment

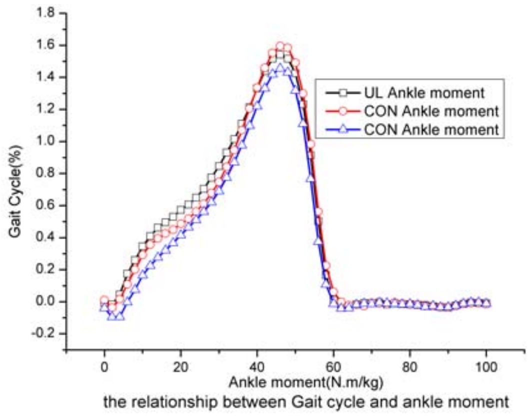

Fig.7: Ankle Moment

5. CONCLUSION

During the walking, the low extremities are synergized by the sequence of the movement. After injured, the change of the gait illustrates kinematics coupling and synergy of low extremities, it not only changes the kinematic of the knee joint, but also the corresponding changes of hip, ankle and even the unaffected limb. The joint angles of the hip and ankle in sagittal changing are due to the knee flexion-extension angle changing as the mechanism compensating. ACL deficiency patients demonstrate a sustained internal knee flexion moment during early mid-stance. The results suggest that quadriceps avoidance as a gait adaptation in ACL-deficient patients may be common as previously reported (Winter, 1989). The compensating changes of knee internal moment due to the knee anterior instability for ACL rupture. The decrease of the maximum of the knee flexion proves the adaptable changes produced by nervomuscular control to reduce the quadriceps contractions, to keep the tibia not to move too far forward.

In short, ACL patients tend to develop a quadriceps-avoidance gait to reduce a quadriceps contraction during walking, the internal knee extension moment reduces considerably or sustained by the flexion moment. Meanwhile it is the compensative strategies that the ankle dorsiflexion moments and hip extension summit rockets sharply.

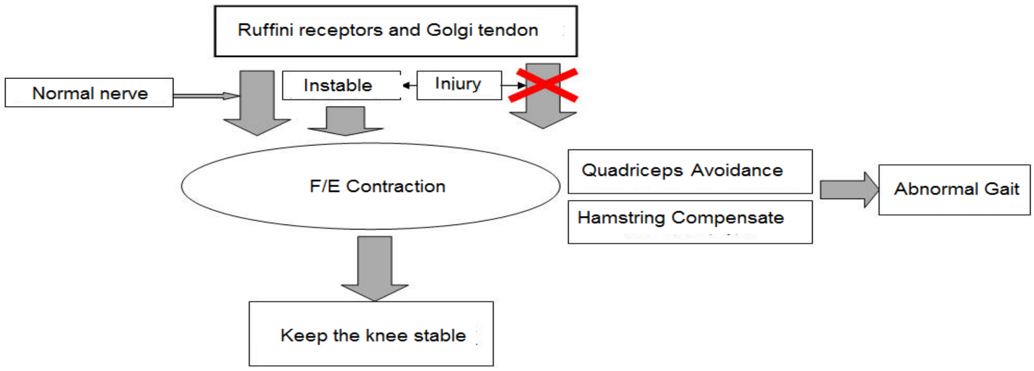

Fig. 8: The adaptive course

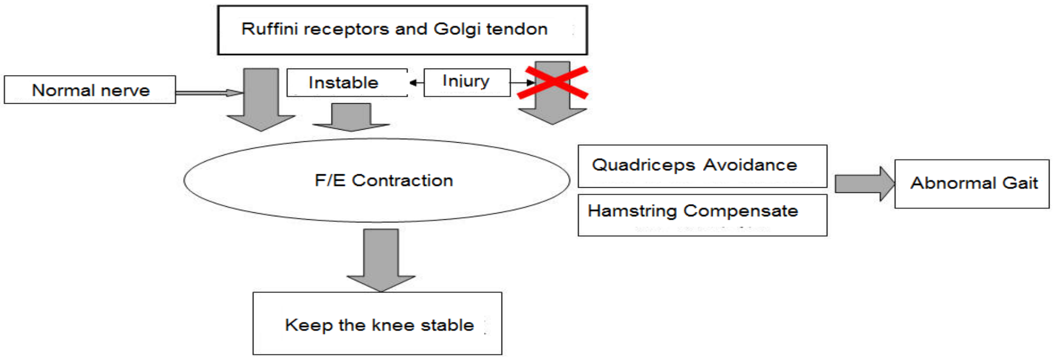

Fig. 9: The course of the quadriceps avoidance

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