Inter-Joint Coordination of the Lower Limb Joints in Patients with Diabetes Mellitus During Obstacle-Crossing

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SUMMARY
Patients with type II diabetes mellitus (DM) have been reported to be at a high risk of falling which may be related to the presence of multiple risk factors, including the disease itself, problems with gait and balance, and peripheral neuropathy (PN). The purpose of this study was to compare the joint kinematics and inter-joint coordination of the lower extremities between healthy subjects and individuals with DM during obstacle-crossing with the leading limb. With significant changes of the joint kinematics, patients with DM changed significantly the way the motions of the lower limb joints were coordinated during obstacle-crossing in a stable fashion. Although the stable inter-joint coordination may enable the patients with DM to accommodate reliably the mechanical demands related to DM complications during obstacle-crossing, the altered inter-joint coordination control with reduced swing toe-clearance may increase the risk of falling during obstacle-crossing. It is suggested that patients with type II DM, with no to minimal PN, should also be targeted for fall prevention.

INTRODUCTION
Inter-joint coordination is the relationship between the motions of two joints, including angular positions and velocities that are associated with not only the effenter motor control, but also information from afferent joint receptors [1]. Since inter-joint coordination provides information on how the neuromusculoskeletal system organizes the redundant degrees of freedom of the joints to achieve a smooth, efficient and accurate functional movement [2], identifying the deficits of the inter-joint coordination in patients with DM may be useful for more insight into the influence of DM-related complications on the control of the motor task. This, together with previous findings, will provide useful information for clinical interventions. Recently, Lu et al. (2008) studied the patterns and variability of the inter-joint coordination of the lower limbs during obstacle-crossing in young adults using the method of relative phase plot, which combines information on joint angular positions and velocities. The variability of the relative phase plots of repeated trials was used to quantify the variability of the inter-joint coordination patterns during the movement as in other previous studies.

With altered joint kinematics and kinetics [3], and with affected sensorimotor function [4], patients with DM are expected to have different coordination patterns with a larger variability during obstacle-crossing. However, no study has investigated the effects of DM complications on the inter-joint coordination during obstacle-crossing. In order to address this issue, the current study aimed to test the hypothesis that DM complications would affect the patterns and variability of the inter-joint coordination in patients with DM during obstacle-crossing, using data collected at the same time in our previous studies [3].

METHODS
In a gait laboratory, each subject walked at a self-selected speed on an 8-meter walkway. A height-adjustable obstacle that was composed of a 1.5 m long aluminum tube with a diameter of 1.5 cm placed across a metal frame. 28 infrared-retroreflective markers with a diameter of 14 mm were used to track the motion of the body segments, including the pelvis, each thigh, shank, foot, the head, upper limb, and the trunk. Three-dimensional marker trajectory data were measured using a 7-camera motion analysis system (Vicon 512, Oxford Metrics Group, UK). Test conditions included obstacle-crossing of three different heights (10%, 20% and 30% of leg length) for both limbs. Six successful trials, three for each leg, for each condition were obtained for each subject.

Each body segment was embedded with an orthogonal coordinate system with the positive x-axis directed anteriorly, positive yaxis superiorly and positive z-axis to the right. A Cardanic rotation sequence (Z–X–Y) was used to describe the rotational movements of each joint. For the angles in the sagittal plane, angular velocities were calculated for each joint using the generalized cross-validatory spline method. Phase plots of angular velocities against angular displacements for each joint were then generated. The phase angle (φ) was obtained from the normalized phase plot of each stride cycle as the angle formed between a line from the origin (0, 0) to the current data point (x, y) and the right horizontal (Fig. 1), or calculated using φ=tan⁻¹(x/y). The calculated phase angles were in the range of 0-180°, with positive values in the first and second quadrants and negative values in the third and fourth ones. Relative phase angles (RPA) between two adjacent joints were then calculated by subtracting the phase angle of the distal joint from that of the proximal, namely hip-knee and knee-ankle. For each inter-joint relationship, the continuous relative phase (CRP) curves from the six trials...
of all subjects were ensemble-averaged for each obstacle height condition to reveal the general patterns of the inter-joint coordination. A parameter called deviation phase (DP) were then calculated by averaging the standard deviations of the ensemble CRP curve points for the stance and swing phase for each obstacle height. A low DP value indicates a more stable relationship between the two joints for the given subject and obstacle height.

**RESULTS AND DISCUSSION**

Compared to normal controls, the DM group had similar walking speeds and horizontal foot-obstacle distances but significantly reduced leading and trailing toe-obstacle clearances, suggesting an increased risk of tripping over the obstacle.

When the swing toe was above the obstacle, patients with DM showed smaller swing hip and knee flexion as well as smaller hip adduction which resulted in reduced trailing toe-obstacle clearance. The two groups had similar inter-joint coordination patterns in the leading limb (Figure 2) while those at the trailing stance knee-ankle and trailing swing hip-knee were different. The DP values of the hip-knee and knee-ankle CRP curves were not significantly different between the two groups. It appears that the DM group adopted a particular biomechanical strategy to cross obstacles with altered but stable inter-joint coordination control. Although the stable inter-joint coordination may enable the patients with DM to accommodate reliably the mechanical demands related to DM complications during obstacle-crossing, the altered inter-joint coordination control with reduced swing toe-clearance may increase the risk of falling during obstacle-crossing.

**CONCLUSIONS**

With significant changes of the joint kinematics, patients with DM changed significantly the way the motions of the lower limb joints are coordinated during obstacle-crossing in a stable fashion. It appears that the DM group adopted a particular biomechanical strategy to cross obstacles with altered but stable inter-joint coordination control. Although the stable inter-joint coordination may enable the patients with DM to accommodate reliably the mechanical demands related to DM complications during obstacle-crossing, the altered inter-joint coordination control with reduced swing toe-clearance may increase the risk of falling during obstacle-crossing. Both normal and reliable inter-joint coordination should be considered as an outcome of therapeutic intervention, and the patterns and variability of inter-joint coordination can be used to evaluate treatment effects.

**REFERENCES**