INVERSE DYNAMIC CALCULATION OF 3D ANKLE JOINT KINETICS DURING GAIT: THE INFLUENCE OF CENTER OF PRESSURE DATA

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The purpose of this study was to investigate the effect of the errors in the center of pressure (CoP) locations on three-dimensional (3D) ankle joint torque during the stance phase of gait. Kinematic and kinetic data from one healthy male subject (age: 22 yrs, height: 180 cm, body mass: 80 kg) were collected. Changes in ankle joint torque, calculated during inverse dynamics, during the stance phase of walking were obtained using simulated CoP data with up to ± 30 mm shifts in antero-posterior and medio-lateral directions. Shift of the CoP in the antero-posterior direction caused a change of magnitude of the plantarflexor torque, while the torque pattern was not altered. On the other hand & change of the ankle inversion/eversion torques were greatly influenced by the CoP shifts in the medio-lateral directions. A shift of ± 10 mm of CoP in the medio-lateral direction caused a switch in the inversion/eversion torque of ankle joint. These results suggest the importance of accurate CoP determinations in inverse dynamics procedures.

KEY WORDS: center of pressure (CoP), inverse dynamics, joint torque, gait

INTRODUCTION: An inverse dynamics analysis is frequently used to determine the joint torques and powers in the field of gait analysis and sports biomechanics (Devita, P.& Hortobagyi T., 2000; Vaughan, C.L.,1996; Iino, Y. & Kojima, T., 2001). Potential sources of error in calculating joint torques include 1) human error in video digitizing processes, 2) individual variation of the anthropometric parameters, 3) disagreement between the space coordinate system (inertial reference frame) and force plate reference frame, 4) unsuitable data smoothing, and 5) error based on the CoP obtained from a force plate. Few studies have reported the effects of error sources on the computed joint torques. McCaw et al (MaCaw, S.T. & Devita, P. ,1995) reported that errors of ± 5 mm and ± 10 mm in the CoP of the ground reaction force caused 7 to 14% changes in the maximum joint torque for the lower extremity during the stance phase of walking and running. However, it was reported that the erro rs in CoP locations would be greater than ± 20 mm according to the equipment and measurement conditions (Kistler.,1984; Bobbert M.F. & Schamhardt, H.C. ,1990). Although there have been several studies about the effect of CoP locations on 2D joint kinetics, the effects on the 3D joint torques have as yet not been reported. The purpose of this study was to investigate the effect of the errors in the CoP locations on 3D ankle joint torque calculations during the stance phase of walking.

METHODS: In this study, static loading calibration on force platform was performed to ascertain the accuracy of CoP location measurement. An aluminum plate with 35 holes with known x and y coordinates was firmly bolted to the top of a force platform (type 9281B, Kistler). The vertical force of 1000N was placed on the steel board exactly above the cylindrical stylus, then the cylindrical stylus was pulled in various directions with a horizontal force of 100N (Figure 1). The standard error of the CoP was X = ± 0.88 mm, and Y = 1.60 mm.
Kinematic and kinetic data were collected for one healthy male subject during the stance phase of walking with a cadence of 100 steps / min. Kinematic data were collected at 60 Hz during the stance phase using four synchronized video cameras. The ground reaction force was measured at 500Hz using a Kistler force platform (type 9281B) which was synchronized with the video cameras using LED flash light. Video images were digitized manually and thereafter the set of two-dimensional coordinate data were converted to 3D spatial coordinates with a DLT algorithm. The mean standard error for the 3D reconstruction was ±3.3 mm for the three directions. Raw data were filtered with a fourth-order, zero-lag Butterworth digital filter with various cut-off frequencies (the mean of 3.7Hz) determined by residual analysis(Winter, D.A.,1990). The joints center locations of the hip, knee, and ankle

were estimated with ARMO software (gsport inc., Japan) using the 3D lower limb model by Delp (http://www.isbweb.org/data/delp/index.html,2005). The location of the center of mass and inertial properties of each body segment were estimated from the BSP of Japanese population reported by Ae(Ae, M.,1996). Changes of ankle joint torque were obtained using ordinary inverse dynamics procedures with 3D kinematic and GRF data, which was reconstructed to 60Hz. Joint torques were also calculated with the simulated CoP data shifted up to ± 30 mm in the antero-posterior and medio-lateral directions.

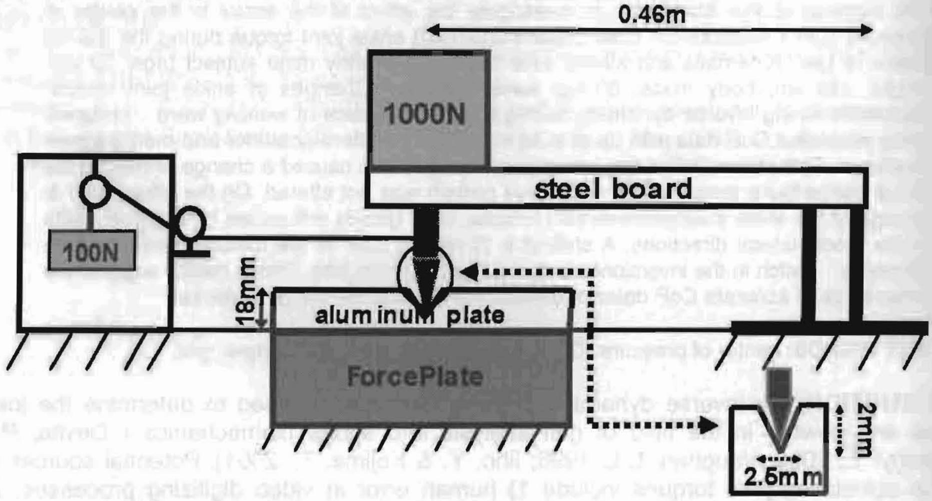

Figure 1 Calibration method of CoP. Vertical static force (1000N) applied over a steel board, supported with a cylindrical stylus which rested in one of drill holes on an aluminum plate bolted to the force plate. Then the stylus was pulled with a horizontal force of 100 N.

RESULTS: Changes of 3D ankle joint torques were similar to those reported previously (MaCaw, S.T., Devita, P. ,1995; Thor F.Besier, Daina L. Sturnieks, Jacque A. Aldersion & David G. Lioyd. 2003; Winter, D.A.,1983). Obvious changes of the ankle joint torques were observed due to the CoP shifts both in the antero-posterior and medio-lateral directions (Fig2). Although the antero-posterior shifts of CoP caused changes in the peak values of the ankle plantarflexor and dorsiflexor torques (-143.0 N·m ~ -94.3 N·m, 19.6% ~ -21.2% with ±30mm shifts), the medio-lateral shifts of CoP did not show obvious changes both in the ankle plantarflexor and dorsiflexor torques (-123.6 N·m ~ -116.0 N·m, 3.6% ~ -3.0%) (Fig2, (2, 4)). The antero-posterior and medio-lateral shifts of the CoP did not cause changes in the time of occurrence of the peak values and the pattern of change in the plantarflexor and dorsiflexor torques. However, the changes of inversion/eversion torques at the ankle joint were greatly influenced by the medio-lateral CoP shift of as little as ±10 mm. The directions of the inversion/eversion joint torque reversed for a CoP shift from medial to lateral directions (Figure 2 (3), Figure 3).

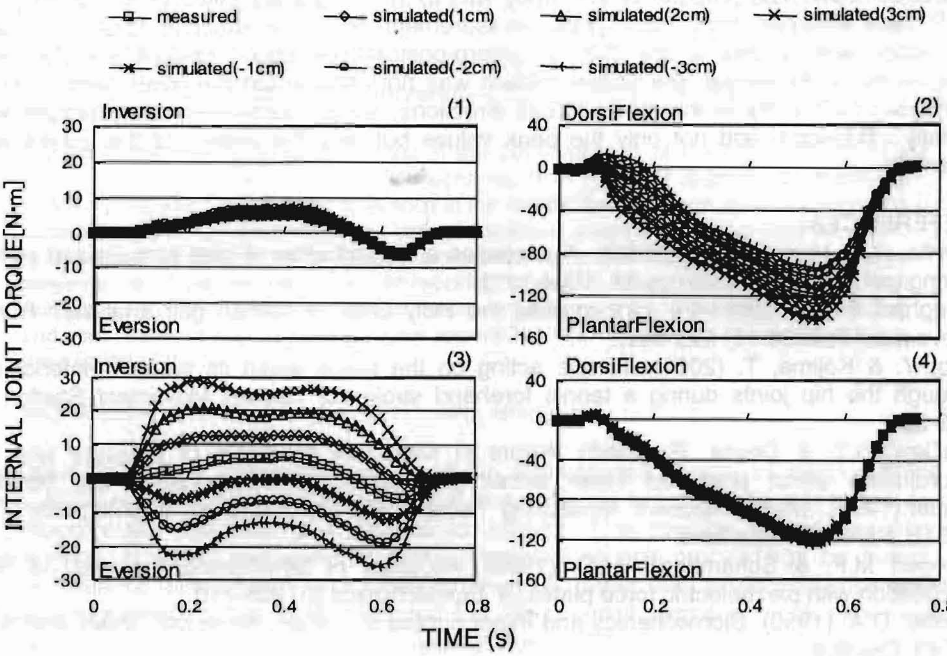

Figure 2 Effect of antero-posterior shifts (1, 2) and medio-lateral shifts (3, 4) in the CoP upon ankle joint torque curves during stance phase of walking.

DISCUSSION: The results demonstrated that accuracy of joint torques largely depends on the errors in spatial measurement of CoP. In particular plantarflexor and dorsiflexor torques were largely affected by CoP shift in antero-posterior directions, and inversion / eversion torques were largely affected by CoP shift in medio-lateral directions. The joint torque values and the changing patterns were more sensitive to errors in the medio-lateral direction than in the antero-posterior direction. The main reason of this fact could be attributed to the differences of the moment arm for the joint torque. The distance from the center of mass of the foot to the point of application of the GRF is generally shorter in the medio-lateral than in the antero-posterior direction during the stance phase. For the purpose of accurate joint torque calculation very precise measurement of CoP locations would be essential. We must make all possible effort to minimize the errors of the CoP locations on force platform measurement in inverse dynamics procedures. For example, the setting up of the forceplate should be consistent with the manufacturers recommendations. Calibration and correction methods for CoP should be developed.

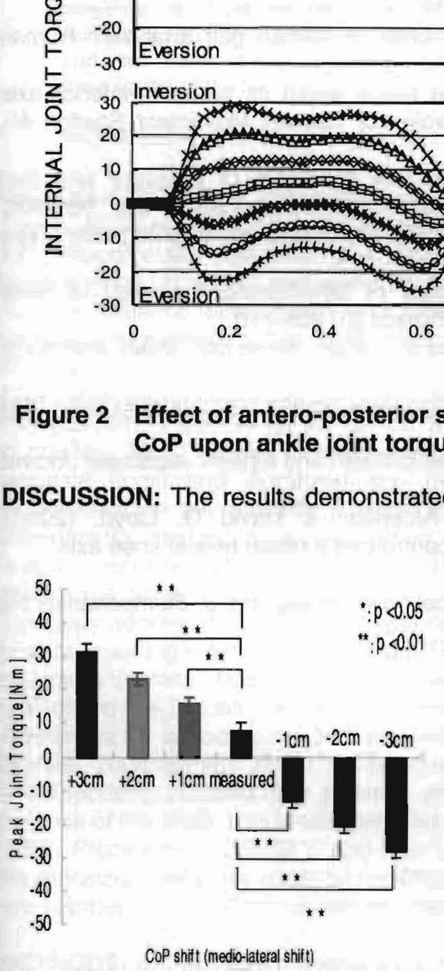

Figure 3 Relationship between peak values of Inversion/ Eversion torques at ankle joint and medio-lateral CoP shift during stance phase of gait.

CONCLUSION: The purpose of this study was to investigate the effect of the errors in the CoP data obtained from force plate measurement on 3D ankle joint torques. Though simulation with a shift of the CoP in antero-posterior directions caused the change of magnitude of the torque, the torque pattern was not altered. On the other hand, with the simulated CoP shifts in the medio-lateral directions, ankle inversion/eversion torques were greatly influenced, and not only the peak values but also the pattern of the curves were changed.

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