JOINT TORQUE INFLUENCES TORSO ANGLE AND IMPACT SEVERITY DURING BACKWARD FALLS

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INTRODUCTION

Fall severity and injury risk depend on a number of host and environmental factors that can include: impact position, fall height, surface stiffness, muscular strength, and bone strength. Knowing the relative importance of these and other factors is critical toward developing intervention strategies. In this regard, validated computer simulations can provide important insight into fall biomechanics by facilitating parametric and sensitivity studies, in which key variables are systematically varied and the consequences quantified. Using this approach, we investigated the relative influence of torque generation at the knee and hip joints on fall mechanics. We focused on two experimental falls resulting in significantly different ground/torso impact angles for a backward fall from a standing height. Specifically, we asked: how does joint torque influence torso angle at impact, and is it preferable to fall upright versus backward leaning when trying to minimize the ground contact force, and hence injury risk?

METHODS

Studies of young female volunteers falling backwards onto a padded mattress were used to validate a computer simulated fall (Tether-release experiments conducted by Robinovitch S. N., currently unpublished). The computer model consists of five rigid bodies (2 lower legs, 2 upper legs, and 1 upper body segment) connected by kinematic joints [1]. This MADYMO model features several improvements over previous fall models [2, 4], including an algorithm for simulating impact and the generation of contact force between the pelvis and the ground (contact stiffness of 71 kN/m, [3]).

For the input of stiffness of the hip and the knee joints of human subjects, this study employs an inverse dynamics algorithm, which "inversely" computes joint stiffness (torque vs. joint angle) based on experimentally measured foot reaction forces and joint rotations.

Model validation focused on two backward falls resulting in different ground/torso impact angles: backward (BWL) and upright (U) falls (Figure 1). In both falls, volunteers were asked to fall as softly as possible by squatting during descent without using their hands to break the fall. The different impact configurations seen in BWL and U are attributed solely to the fall strategy of the volunteer. Given the joint stiffness characteristics, body mass and height, body position (5 degree initial lean), and initial velocity (stationary), the MADYMO model simulates the resulting fall kinematics and computes vertical pelvis velocity at impact, peak contact force, joint work, and kinetic energy pre- and post-impact.

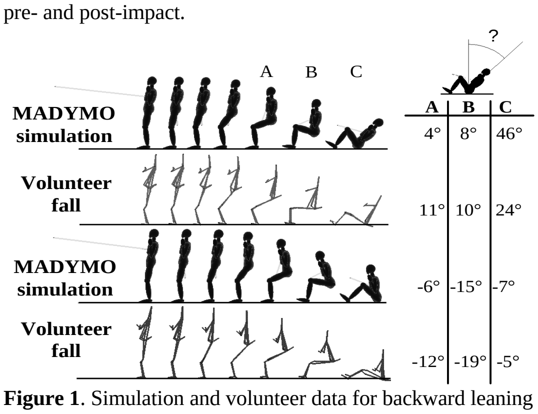

Figure 1. Simulation and volunteer data for backward leaning (BWL) fall (top figures) and upright (U) fall (bottom figures).

ESSENTIAL RESULTS

The validation simulations achieved excellent agreement with the volunteer data for both the BWL and the U falls (Figure 1). The simulated pelvis velocities of 2.0 and 2.6 m/s for the BWL and U falls, respectively, also closely approximate the volunteer data; these velocity values are also in agreement with published data [2].

In both volunteer fall configurations, the knee and the hip underwent flexion rotations while exerting eccentric extensor (braking) torques. Of note is that these exerted hip and knee torques, ranging from 20 – 45 Nm (per joint), constitute a small fraction (15% – 35%) of the peak attainable joint torques measured in young healthy females under isometric conditions. These joint parameters are consistent with prior observations [2].

The volunteer in the BWL fall generated knee torque comparable to that of the U fall, but exerted greater hip extensor torques. This shows that an increase in the hip torque increases the lean back angle, ? (? = 0 means the torso is vertical; ? > 0 means the torso is leaning backwards). A sensitivity analysis showed that decreasing the knee torque, while controlling the hip torque, also increases the lean back angle.

Our simulations demonstrate that more joint work was performed during the BWL fall (due to greater hip torque) while more potential energy remained for the U fall at impact (due to smaller change in cg height). Consequently, there was a comparable amount of kinetic energy (KE) at impact for the two cases. Despite this, less KE was dissipated in the BWL impact, and the corresponding vertical impact velocity and peak contact force were less (Figure 2).

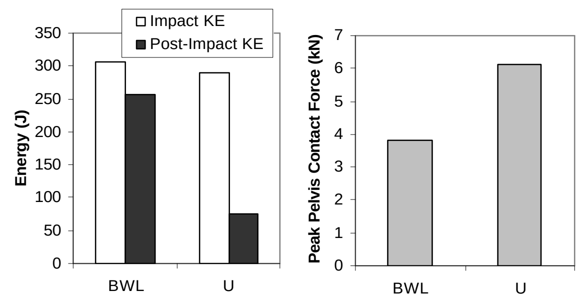

Figure 2. Energy and force comparison for BWL fall versus U fall.

DISCUSSION

Our findings suggest that while controlling for other factors, an upright fall produces a higher pelvis contact force than a backward leaning posture. This decrease in contact force for the BWL case results primarily from a lower effective mass for the leaned back posture; thus, a person falling with a BWL posture absorbs less KE during impact (Figure 2). This finding supports the observation of van den Kroonenberg, et al which utilizes a two link model to conclude that the increased effective mass during U falls results in higher impact forces [4]. Importantly, our results demonstrate that the relative magnitudes of joint torque in the hip and the knee significantly affect the resulting fall configuration, which in turn affects contact force.

The greater residual KE in the BWL fall would increase the potential for a subsequent, post-impact injury, such as head impact. However, in an accidental fall, head impact could be avoided by breaking the fall with the outstretched hands in both configurations.

Although we have made a number of simplifying assumptions, our results demonstrate the value of a parametric study. Our unexpected finding - that even though the pre-impact KE in the two fall configurations were comparable, the impact force was greater for the U case - was explained by differences in effective mass and energy dissipation. While based on only a limited number of volunteer studies, the computer simulation sheds insight into factors that most influenced impact severity and thereby provides the foundation for future intervention studies.

ACKNOWLEGMENTS: NIH Grant AR46890

REFERENCES

1 MADYMO; Mathematical Dynamic Model, Version 5.4 (1999), TNO Road-Vehicles Research Institute, The Netherlands
2 Sandler R. & Robinovitch S. (2001), *ASME J. Biomech. Eng*., Vol 123, pp 590-598.
3 Robinovitch S. N., Hayes W. C., McMahon T. A. (1991), *ASME J. Biomech. Eng*., Vol 113, pp 366-374.
4 van den Kroonenberg A. J., Hayes W. C., McMahon T. A. (1995), *ASME J. Biomech. Eng*., Vol 117, pp 309-318.

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