C11 Biomechanical Determinants of Injuries From Low-Level Falls

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The goal of this presentation is to present a review of published scientific research in order to enhance the ability of the forensic biomechanist to determine if a mechanism was present to cause injury in a lowlevel fall.

Reliance on published scientific research by the forensic community should enhance the ability to accurately assess whether a mechanism of injury was present in a low-level fall. This presentation will impact the forensic community and/or humanity by demonstrating that caution must be exercised, however, when using published data to perform the converse task, that is, to retrospectively predict injury from a given fall. This is very complicated task dependent on many variables including the large number of biomechanical factors affecting injury potential and the wide range of injury types in the literature.

The impact energy available from a standing height fall is derived from a conversion of the potential energy of the body's initial center of mass and can be sufficient to cause significant injury, including fracture of the proximal femur,[1] distal radius,[2] lumbar vertebral body,[3] or skull;[4] but the majority of falls are arrested safely without injury. Fall-related injuries occur when the impact forces and moments exceed an individual's biological tissue tolerance to injury. DeGoede et al.[5] and Robinovitch et al.[6] provide excellent review articles that document biomechanical factors contributing to injury severity in nonsyncopal falls to the ground. This paper will not address all of these biomechanical factors; rather it will highlight some of those factors that have experimental support in the scientific literature.

Direction of fall can influence both the primary location of impact to the body in a fall and the subsequent injuries. Smeesters et al.[7] found that human subjects exposed to trips and unanticipated step-downs during gait usually fell forward or sideways, whereas those exposed to slips more often fell backward or sideways. Hsaio & Robinovitch[8] analyzed body segment kinematics in young subjects during induced forward, backward and sideways falls. In all falls, impact to the outstretched hand(s) was observed. All posterior falls also resulted in contact with the pelvis. In greater than 70% of the falls with pelvis contact, the time difference between hand and pelvis impact was less than 50 ms. The investigators theorized that this short interval between multiple impact points suggested a sharing of impact energy between the upper extremities and pelvis which would likely reduce the injury risk compared to a single impact point. The higher incidence of fracture seen in the elderly population may be partly explained by slower upper extremity reaction times or landing on the hip instead of the buttocks in a low-level fall.

Extremity joint and soft tissue properties also govern extremity impact force, energy absorption and injury potential. Chiu and Robinovitch,[2] using a mathematical model to simulate a forward fall from standing height (0.75m) onto an outstretched hand, showed large differences in the impact response between the wrist and shoulder. Peak impact forces measured in the wrist (2.57 kN) surpassed the average fracture force for the elderly distal radius (2.26.+ 1.01 kN), but these large peaks were not transmitted proximally to the shoulder. The shoulder underwent larger displacements and absorbed more energy (277 J) than the wrist likely due to lower shoulder stiffness. This would result in a higher potential for shoulder joint injury (e.g., rotator cuff tear or capsular instability). Altering the extrinsic properties of the impact surface with padding reduced the peak impact force at the wrist by about 35%,[9] to a level that might prevent wrist injuries in standing height falls. Unfortunately, padding did not generate a concomitant reduction in force or deflection at the shoulder. A similar phenomenon has been observed in experiments measuring peak head and neck loads following vertical drops on the vertex of cadaveric heads with an average impact velocity of 3.12 + 0.18 m/sec onto unpadded and padded surfaces.[10] Padding reduced peak force at the head but increased the impulse and catastrophic injuries in the cervical spine.

Volitional momentum arrest or energy dissipation strategies prior to impact have also been identified in the scientific literature. Robinovitch et al.[11] showed that individuals have some control over the magnitude of impact energy applied to their body during a low-level fall. In their study these investigators simulated different reaction time delays to a fall by asking standing human subjects to fall backward onto their buttocks as softly as possible without use of their hands from 3 different initial backward lean angles (Oº, 5º, and 12º). An increased initial lean angle resulted in significantly increased vertical hip impact velocity and kinetic energy at impact, and decreased energy-absorbing work at the hip, knee, and ankle joints during descent. The increased lean reduced the available reaction time and diminished the subjects' ability to reduce impact energy through a protective "squat" response that consisted of lower extremity muscle contractions. The importance of reaction time was also illustrated in research by van den Bogert et al.[12] who used an inverted pendulum model to show that faster response time was more important than slower walking velocity for successful recovery from a trip in older adults. The results of these studies highlight the importance of intrinsic variables, such as reaction time, strength and flexibility, in determining one's ability to not only avoid falls but also dissipate energy and affect impact severity in a low-level fall.

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Anthropometry is a biomechanical variable that also influences injury risk. Research has found a correlation between body mass index (BMI) – weight (kg) divided by height^2 (m) – and ankle fracture severity in low-level falls.[13] A BMI of 18 – 25 kg/m^2 is considered desirable for both men and women. In this study 24 patients with displaced malleolar fractures were matched with 24 patients with undisplaced fractures. The mean BMI of patients with displaced fractures (28.25 kg/m^2) was significantly higher than that (24.58 kg/m^2) of those with undisplaced fractures. These findings suggest that obesity is a risk factor for severe ankle fractures in low-level falls.

Bone properties represent another biomechanical variable that contribute to the risk of injury from a low-level fall. Salminen et al.[14] investigated 50 femoral shaft fractures from low-energy falls in a patient population with an age range of 17-92 years. In 38 patients the fall height was ground level. The significant biomechanical determinant of fracture in this study was the presence in 64% of the patients of at least one preexisting factor, besides age, likely to cause osteopenia, a condition which weakens the mechanical strength of the femur.

In summary, reliance on published scientific research by the forensic community should enhance the ability to accurately assess whether a mechanism of injury was present in a low-level fall. Caution must be exercised, however, when using published data to perform the converse task, that is, to retrospectively predict injury from a given fall. This is very complicated task dependent on many variables including the large number of biomechanical factors affecting injury potential and the wide range of injury types in the literature.

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